A

MAJOR PROJECT

ON

DIFFERENT LANDFILL LINER MATERIALS: A COMPARATIVE STUDY

Submitted in Partial Fulfillment of the Requirement

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MASTER OF ENGINEERING

(ENVIRONMENTAL ENGINEERING**)**

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CERTIFICATE

It is certified that the work presented in this thesis entitled **“Different Landfill Liner Materials: A Comparative Study”** by Rahul Dandautiya University Roll no. 18701 in partial fulfillment of the requirement for the award of degree Master of Engineering in Environment Engineering, Delhi College of Engineering, Delhi, is an authentic record. The work is carried out by him under our guidance.

The work embodied in this major project has not been submitted for the award of any other degree to the best of my knowledge.

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ABSTRACT

Any waste material stored in a landfill poses potential problems. The one of major problem is the possible contamination of soil, surface water and groundwater. It may happen when leachate produced by water or liquid wastes moving inside, through and escape out of the landfill and then migrates into areas adjacent to the landfill.

Municipal solid waste landfill needs a liner that separates the waste from the groundwater system. A liner is signified to minimize the migration of contaminants from the MSW. The migration of leachate below the clay liners can be prevented by using natural clay deposits, compacted clay, geosynthetic materials or mixer of them of a certain minimum thickness as a liner material.

The purpose of this study is to provide an approach for comparing the performance of geosynthetic clay liners (GCLs) compacted clay liners (CCLs) and geomembrane used in the form of landfill liners material. Transport of solute is happens in porous media by two basic processes: diffusion and advection. An advection dispersion equation of second order one dimensional is used to compare.

To examine the performance of these liner materials a MATLAB program is made. The solution is done analytically with the using of erfc function. Graphs and data sheets are prepared for different liner materials. These data provide significant results about the behavior of liner material. The transport rate of solute through the liner material is compared by using their effective porosity, tortuosity and effective molecular diffusion coefficient.

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Nomenclature

n_e	Effective Porocity
τ	Tortuosity
D_{eff}	Effective Molecular Diffusion Coefficient
C	Concentration of Solute
t	Time
D	Hydrodynamic Dispersion Tensor
v	Seepage Velocity
R	Retardation Factor
ρ_d	Dry Unit Weight of Soil
K_d	Partition Coefficient
n	Porosity

CHAPTER 1
INTRODUCTION

1.1 INTRODUCTION:

All types of waste that arising from human and animal activities, in solid or semi solid form, called solid waste. It is defined as discarded solid part that produced from domestic, industrial, agricultural, institutional, commercial, trade, agricultural, mining activities and public services. Solid waste includes domestic waste, municipal waste, commercial waste, garbage (animal and vegetable waste), rubbish (inorganic excluding ashes), ashes, industrial waste, sludge from wastewater treatment plants etc. The population living in the urban area produces much more solid waste than the rural one. Hence the solid waste problem is mainly related to the cities or towns and as the cities are increasing the problem is being worsened. Process used to handle the problem of solid waste in an efficient manner, known as the solid waste management. This management is a part of public health and sanitation as per the Indian constitution. According to the manual on Municipal Solid Waste Management, Government of India, the solid waste can be classified as Domestic/Residential waste, Municipal waste, Commercial waste, Institutional waste, Garbage, Rubbish, Ashes, Bulky waste, Street sweepings, Dead animals, Construction, and demolition waste, Industrial wastes, Hazardous waste and Sewage waste.

1.2 SOLID WASTE MANAGEMENT METHODS:

The methods used for the management of the solid waste are land-filling, composting, windrow composting, incineration and recycling.

1.2.1 Composting:

In composting the organic matter present in solid waste, has been decomposed and recycled as a fertilizer for soil amendment. The compost is a key ingredient in organic farming. The composting process needs mainly piling up waste outdoors and waiting a year or more. The process used in the modern methodical composting is a multi-step, closely monitored process with measured inputs of water, air and carbon and nitrogen-rich materials. The process of decomposition is joined by shredding the plant matter, adding water and the proper aeration, is ensured by regularly turning the mixture. The further breakup of material is done by worms and fungi. The chemical process is managed by aerobic bacteria that convert the inputs into heat, carbon dioxide and ammonium. In the next phase ammonium is further converted into plant-nourishing nitrites and nitrates through the process of nitrification by bacteria. Compost can be rich in nutrients. It is used in gardens, landscaping, horticulture, and agriculture. The compost itself is beneficial for the land in many ways, including as a soil conditioner, a fertilizer, addition of vital humus or humic acids, and as a natural pesticide for soil. In ecosystems, compost is useful for erosion control, land and stream reclamation, wetland construction and as landfill cover.

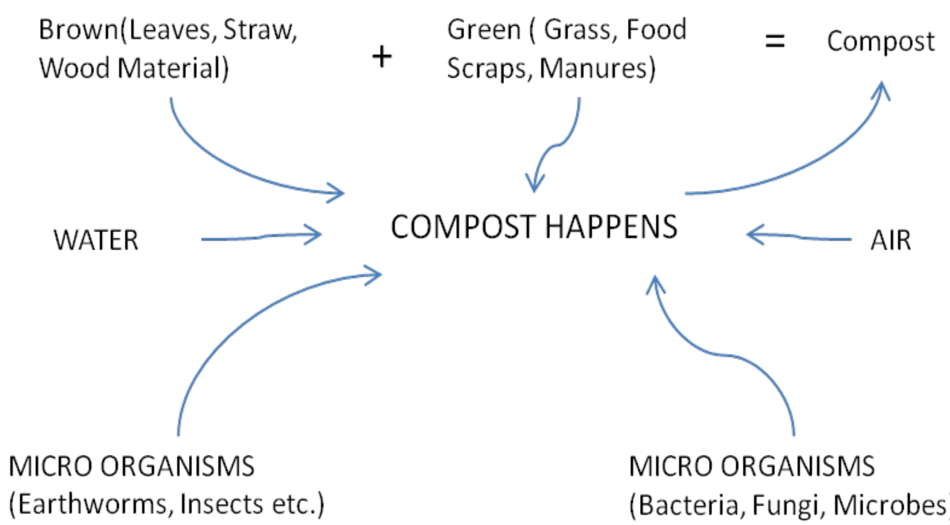


Fig. 1.1 Process of Composting

Following are the forms of composting used now a day:

i. Barrel composting
ii. Vermi composting
iii. Pit composting
iv. Manual windrow composting
v. Mechanical windrow composting
vi. Compost chute
vii. High-tech aerated static pile composting

1.2.2 Incineration:

Municipal solid waste (MSW) incineration plants tend to be among the most expensive solid waste management options, and they require highly skilled personnel and careful maintenance. For these reasons, incineration tends to be a good choice only when other, simpler, and less expensive choices are not available. In the Incineration process of waste treatment involves the combustion of organic substances contained in waste materials. Incineration and other high temperature waste treatment systems are described as "thermal treatment".

All waste disposal alternatives eventually decompose organic materials into simpler carbon molecules such as CO_2 and CH_4. The balance between these two gases and time frame for the reactions varies alternatively. Incineration provides the best way to eliminate methane gas emissions from waste management processes. Furthermore, energy from waste projects provides a substitute for fossil fuel combustion. These are many ways by which incineration helps to reduce greenhouse gas emissions. One of the most attractive features of the incineration process is that it can be used to reduce the original volume of combustible matter by 80 to 95 percent. In the implementation of incineration of solid waste disposal air pollution is a major problem. Incineration of waste materials converts the waste into ash, flue gas, and heat. The formation of ash is mostly done by the inorganic constituents of the waste, and may take the form of solid lumps or particulates carried by the flue gas. It should be take in mind that cleaning of flue gases and particulate pollutants must be done before they are dispersed into the atmosphere. In some cases, the heat generated by incineration can be used to generate electric power.

1.2.3 Recycling:

In the process of recycling the waste, used materials are converted into new products. It is done to prevent the wastage of potentially useful materials.

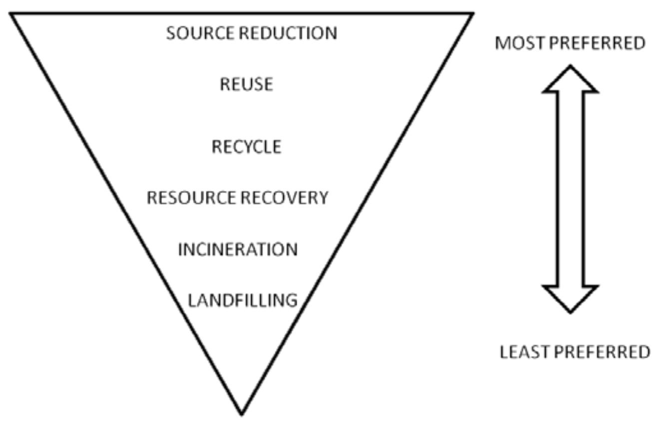


Fig. 1.2 Waste Management Pyramid

By recycling, the consumption of fresh raw materials, energy usage reduces, reduction in air pollution as compare to incineration and reduction in water pollution by reducing the need for "conventional" waste disposal, and lower greenhouse gas emissions as compared to virgin production. It is a key component of modern waste reduction. There are many different types of materials included in recyclable materials like glass, paper, metal, plastic, textiles, and electronics.

1.2.4 Landfilling:

It is a carefully depression in the ground (or built on top of the ground) and wastes are poured in it. The main aim is to prevent any hydraulic connection between the wastes and the surrounding environment, mainly groundwater. The control for the exposure of the environment and humans to the detrimental effects of solid wastes placed on the land is done by sanitary landfilling. By the sanitary landfilling disposal is done in a way such that contact between wastes and the environment reduced significantly and the concentrated wastes are in a well defined area. That results a good control of landfill gas and leachate, and limited access of vectors (e.g., rodents, flies, etc.) to the wastes. The use of sanitary landfilling should be adopted in accordance with other modern waste management strategies that emphasize waste reduction, recycling, and sustainable development.

Waste material stored in landfills that give potential problems. One of the major problems is the possible contamination of soil, groundwater and surface water. It may happen as leachate produced by water or liquid wastes moving into the landfill, through the landfill and out of the landfill, at last migrates into adjacent areas. This type of problem becomes more important especially when industrial wastes are involved because many of these substances are resistant to biological or chemical degradation and, due to this these are expected to persist in their original form for many years, perhaps even for centuries.

1.2.4.1 Leachate Formation:

The leachate is generated mainly by precipitation percolating through waste deposited in a landfill. When anything contacted with decomposing solid waste, the percolating water becomes contaminated and if it then flows out of the waste material it is called leachate. The extra leachate volume is produced during this decomposition of carbonaceous material producing a wide range of other materials including methane, carbon dioxide and a complex mixture of, aldehydes, organic acids, alcohols and sugars. The organic acids produced cause solubilization of various organic as well as inorganic pollutants, in other words leaching of pollutant. This leached mixture is called leachate and considered as cocktail of chemicals.

Leachate has been generated ever since man first assembled to form settlements and pits or created manure heaps. The size and scale of these activities was small which could have created no significant impact other than potentially the positive enhancement to nearby plant growth by locally elevating nutrient levels.

Due to high content of ammonium ions and organic compounds leachate is highly polluted. As leachate move downwards into ground water table from landfill as a result of infiltrated precipitation, ground-water gets contaminated and if the waste is concealed below the water table the ground-water becomes contaminated after leaching compounds from it. As the sources of our potable water are ground water and surface water, they should be protected from such pollutants otherwise the cost of treating drinking water will rise and due to this the life of biodiversity in surface water bodies will be endangered.

Leachate solution formed when water percolates through a permeable medium. In some cases the leachate may be toxic or carry bacteria when derived from hazardous solid waste. The time when a new landfill gets the first waste for a short period, less than a week in hot conditions and even while in transit in tropical the degradation of the putrescible matter present in the solid waste begins. The levels of the various contaminants may be quite low until degradation starts, but they increase very rapidly and the acetogenic stage commences. Acetogenic stage is basically a stage when one of aerobic bacterial fermentation taking place on the chemicals released from the cells which have rapidly died and ruptured their chemical contents into the highly odorous leachate. The pH level falls in any fermentation the pH and hazardous metals may then be dissolved in significant concentrations. The red and rusty hue of leachate wherever it leaks, or breaks comes out of landfills because of dissolving of iron in large amount. A generalized pattern of leachate formation is presented in Figure 1.3.

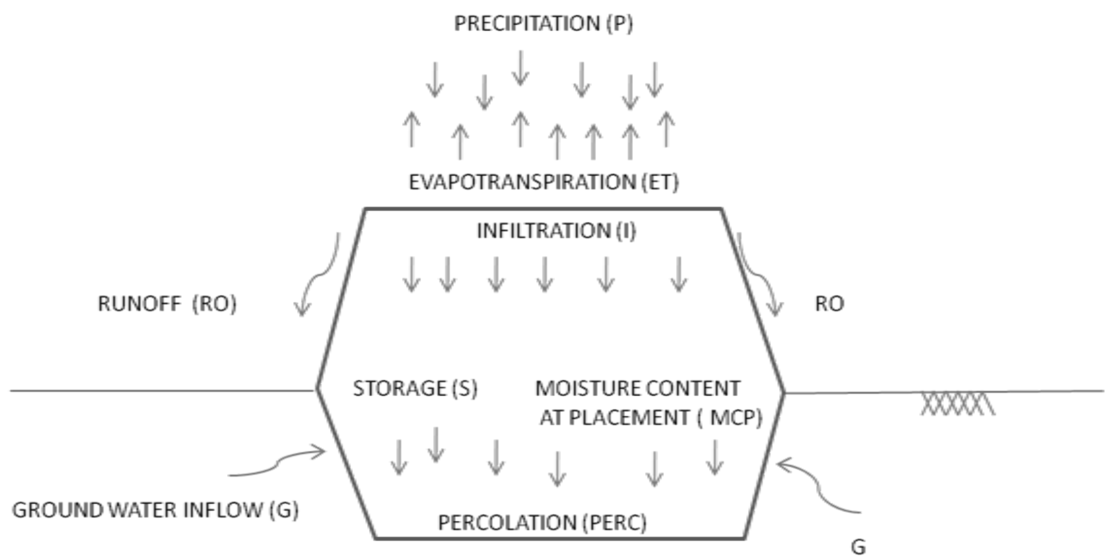


Fig. 1.3 Pattern of Leachate Formation in Landfill

The waste mass starts in an aerobic (aerated) environment and much oxygen is chemically bound into the waste mass, available at the start. However, sooner or later (due to many factors including ambient temperature, rate of waste input, waste composition, etc) the oxygen demand exceeds the available oxygen, and the waste mass turns anaerobic. This is called the start of the methanogenic or methane generating stage, but generation of methane will only commence in an anaerobic landfill when a sufficiently large population of methanogenic organisms (methanogens) are present.

The methanogenic phase will then continue for large time duration, with the methane generation rate rising to a peak and then diminish. Between these periods the ammonical nitrogen concentration will not significantly reduced. In the end when the methanogenic phase ends, air will again percolate into the waste mass without being consumed and aerobicity will be finally return again.

The components shown in fig.1.3 include the following steps:

i. Precipitation (P) falls on the landfill and some part of it becomes runoff (RO).
ii. Some of Precipitation infiltrates (I) the surface (uncovered refuse, intermediate cover, or final cover).
iii. Some of infiltrates evaporates (E) from the surface and (or) transpires (T) through the vegetative cover if it exists.
iv. Some of infiltrates may make up a deficiency in soil moisture storage (S) (the difference between field capacity (FC) and the existing moisture content (MC)).
v. The remainder of infiltrates, after evaporation, transpiration, and soil moisture storage have been satisfied, moves downward forming percolate (PERC) arid eventually leachate (L) as it reaches the base of the landfill.
vi. PERC may be augmented by infiltration of groundwater (G). The procedure used to analyze these processes is referred to as a water balance (WB), various forms of which are commonly used for the simulation of surface water hydrology. The algebraic statement of this form of water balance is:

$$\mathbf{PERC = P - RO - ET - AS + G}$$

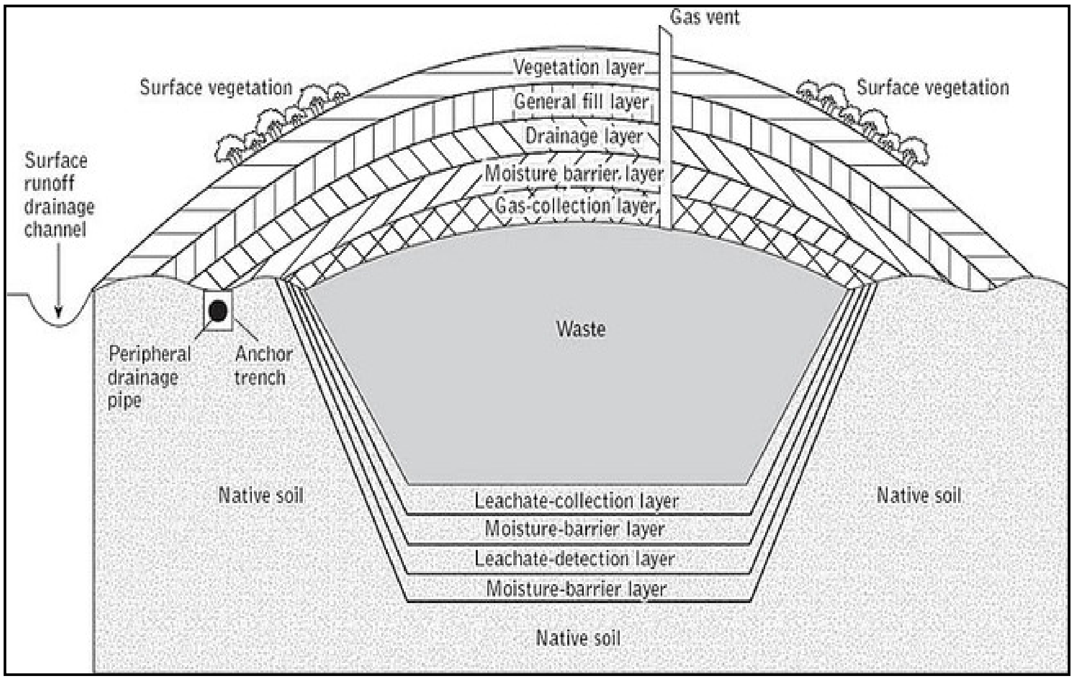
1.3 OVERVIEW OF TYPICAL ENGINEERED LANDFILL LINER SYSTEM:

To trap the path of leachate that migrate through soil strata and contaminate the ground water a proper engineered landfill is required. A well engineered landfill can handle the contamination from hazardous toxic wastes, subjected to leaching by percolating water derived from rain, migrated from landfills, lagoons or dumps of refuse or garbage. It is definitely one of the most burning problems to the ground water system. Structure made of both natural and synthetic materials that is designed and operated to contain waste in an environmentally safe manner. An engineered landfill is sited, designed, constructed, and operated to minimize generation of leachate, migration of leachate and minimum exposure of landfilled waste to the environment that reduces the vectors disease. In the modern landfill, it takes account the nature of the waste that it will contain in its design. For hazardous waste, Landfills are generally designed with greater consideration for safety than for municipal waste. In the industrially developed areas more attention is given to safety in the design of landfills for municipal waste because municipal waste commonly contains hazardous chemicals, such as insecticides, herbicides, paints, and solvents.

In fig. 1.4 different components of an engineered landfill liner system are shown. At top upper portion there is a cover liner that has a vegetative layer and a moisture-barrier layer. In most of the cover liners there are (from top to bottom) a vegetative layer, a general fill layer, a drainage layer, a moisture-barrier layer, and an LFG collection layer. A layer of biotic barrier may also be used above the drainage layer in a landfill, where burrowing animals or plant roots might damage the moisture-barrier layer.

To prevent the erosion by wind and rain vegetative layer is grown on the cover liner. It is suitable for supporting grass and made of soil. The thickness of the root zone for the grass to be grown on the cover liner determined the thickness of the vegetative layer. The next layer that is general fill layer provides additional moisture storage for vegetation, extra space for development of the roots of vegetation so there can be possibility of vegetation other than grass for aesthetic purposes. A typical landfill lining system is shown in fig 1.4.

There are different layers in a typical engineered landfill. The biotic barrier layer is a layer of stones that prevents burrowing animals and plant roots from reaching and damaging the moisture-barrier layer. A biotic barrier layer may also be designed to act as a drainage layer. The biotic barrier layer and other layers of gravelly material in the cover and bottom liners are separated from layers of fine-size materials, such as the general fill layer, by a layer of a geosynthetic fabric. A geosynthetic fabric allows liquids and gases to pass across its thickness without letting the fine-size material fill up the pores in the gravel layer.



Source: *http://science.jrank.org/article_images/science.jrank.org/landfill-techniques.1.orig.jpg*

Fig. 1.4 Components of Modern Engineered Landfill liner System

The drainage layer minimizes gathering of water over the moisture-barrier layer by facilitating lateral flow of water towards drain pipes within and at the periphery of the cover liner. Reducing the height and duration of water gathering over the moisture-barrier layer reduces leakage of water through the moisture-barrier layer to the trapped waste. The material by which drainage layer made is having hydraulic conductivity greater than those of the general fill and the moisture-barrier layers. Sand and gravel are typically used to build the drainage layers, but using geosynthetic materials is better option for this purpose. The drainage layer thickness is determined by the slope of the cover liner, the length of the slope, and the hydraulic conductivities of the materials that going to be used in the drainage layer.

The leakage of water from the drainage layer is minimized by moisture-barrier layer to trap waste. This layer is made of materials with very low hydraulic conductivities, such as compacted clay, a geosynthetic clay liner (GCL), a geomembrane, or combination of these. The moisture-barrier layer design is depends on several factors like the availability of clay of low hydraulic conductivity in the area of the landfill, use of different materials of construction, like GCL and a geomembrane and their hydraulic conductivities. It is also depends on the height to which water is expected to pond in the drainage layer and the acceptable rate of leakage through the cover liner.

Table 1.1 Composition of Leachate from New and Mature Landfills

CONSTITUENT	NEW LANDFILL (LESS THAN 2 YEAR OLD)		MATURE LANDFILL (MORE THAN 10 YEAR OLD)
	RANGE	TYPICAL	
BOD_5	2,000 – 30,000	10,000	100 – 200
TOC	1,500 – 20,000	6,000	80 – 160
COD	3,000 – 60,000	18,000	100 – 500
TOTAL SUSPENDED SOLIDS	200 – 2,000	500	100 – 400
ORGANIC NITROGEN	10 – 800	200	80 – 120
AMMONIA NITROGEN	10 – 800	200	20 – 40
NITRATE	5 – 40	25	5 – 10
TOTAL PHOSPHORUS	5 – 100	30	5 – 10
ORTHO PHOSPHORUS	4 – 80	20	4 – 8
ALKALINITY AS $CaCO_3$	1,000 – 10,000	3,000	200 – 1,000
pH	4.5 – 7.5	6	6.6 – 7.5
TOTAL HARDNESS AS $CaCO_3$	300 – 10,000	3,500	200 – 500
CALCIUM	200 – 3,000	1,000	100 – 400
MAGNESIUM	50 – 1,500	250	50 – 200
POTASSIUM	200 – 1,000	300	50 – 400
SODIUM	200 – 2,500	500	100 – 200
CHLORINE	200 – 3,000	500	100 – 400
SULFATE	50 – 1,000	300	20 – 50
TOTAL IRON	50 – 1,200	60	20 – 200

Values in mg/l except pH, which has no unit

Source: Integrated Solid Waste Management by ***GEORGE TECH0BANOGLOUS, HILLARY THEISEN, SAMUEL A.VIGIL.***

1.4 OBJECTIVES OF STUDY:

Objectives of the thesis are:

i. To study different liner materials.
ii. The application of analytical method to assess contaminant migration through saturated homogeneous liner material.
iii. To study the performance of various liner materials with respect to contaminant migration.

CHAPTER 2
LITERATURE REVIEW

2.1 INTRODUCTION:

In the literature review the aims is to review the critical points of current knowledge including substantive findings as well as theoretical and methodological contributions to this topic. In the field of landfill process of solid waste management and handling of leachate properly significant research works have been done.

2.2 VARIOUS RESEARCHES:

Alexander et al. (1985) gave a new design approach of landfill leachate liner design of a series of V-shaped elements constructed from an impervious membrane, a boxed soil layer saturated with clean water, and a gravel layer. The Study proposed a new type of design for landfill leachate collection systems and certain features of it are examined under certain idealized boundary conditions, the diffusion mass transport of a contaminated liquid through the clean water of the soil layer is studied and by this we can easily determine whether the membrane would remain impervious or crack. This study give an idea to choose an impervious liner material and to collect the leachate for treatment the lined landfill site is more advantageous.

Benson (1993) analyzed hydraulic conductivity of 57 landfills. He summarized statistical characteristics of the data; performed goodness-of-fit analyses on each set to determine a distributional form that can be used to describe spatial variability of hydraulic conductivity. The goodness of fit tests show that the two-parameter log-normal hypothesis is often rejected. The traditional two-parameter log-normal distribution is compared to four alternative distributions: the three-parameter log-normal, generalized extreme value (GEV), the three-parameter gamma, and inverse Gaussian. The analyses show that the three-parameter log-normal and GEV result in superior fits to the data.

McEnroe (1993) derived depths over a landfill liner analytically by explicit formula for the steady-state maximum saturated from basic principles of unconfined seepage. He used extended form of the Dupuit discharge formula to describe lateral drainage over the. The liner is modeled as an impervious sloping plane and accordingly the factors that determine the maximum saturated depth over the liner are the rate of vertical inflow to the drainage layer, the hydraulic conductivity of the drainage layer, the slope of the liner, the maximum distance of flow, and the hydraulic condition at the downstream end of the drainage layer.

Mariusz Kaczmarek and Tomasz Huckel (1998) analyzed chemistry of pore fluid in clayey soils and said that the consolidation is of it is caused by changes in chemistry of pore fluid. It is due to changes in the concentration of various species in the solution and result primarily from a stress-independent deformation of individual clusters, and from a mechanical weakening or strengthening of the clay solid matrix in the presence of stress. He proposed an extension of Terzaghi's model of the mechanical consolidation to merge chemical loading of soil. He concluded that there is a strong dependence of distribution of pore pressure on the chemical load and chemically induced settlements of soil.

Loretta Y. Li and Guangxi Wu (1999) used a multi component reactive solute-transport model and studied the migration of dissolved heavy metals (Cd^{2+}, Pb^{2+}, Cu^{2+}, and Zn^{2+}) in a clay barrier subject to two leachates having different pH values. It can handle simultaneous simulating of water flow, advection-dispersive solute transport, and chemical reactions. The simulations were focused on the concentration of metals in the simulated clay barrier. His results indicates that in neutral leachate the heavy metals mobility follows the lighter one ($Cd^{2+} < Pb^{2+} < Cu^{2+} < Zn^{2+}$) and with an acidic leachate the order changed ($Pb2^{+} < Cu^{2+} < Zn^{2+} < Cd^{2+}$).

Despina et al. (1999) did study on the landfill leachate and its impact on the groundwater quality of the greater area. They examine the Ano Liosia landfill site in Greece that receives the domestic waste from an urban population of nearly 3,500,000 inhabitants and area of 173 ha. The organic load appeared to be quite high and the BOD_5/COD ratio confirmed the fact that the landfill operates in its last phase and, furthermore, the majority of the organic matter is not easily biodegradable. The high chloride concentrations constitute a serious threat for the aquifer of area while heavy metals were in low levels with the exception of load.

Rowe et al. (2000) described procedure and apparatus for performing tests to obtain inorganic diffusion coefficients for Geosynthetic Clay Liners (GCLs) are, and the processes (diffusion, anion exclusion and osmosis) that can affect the interpretation of these tests are discussed. Results from several inorganic diffusion tests on GCL and bentonite specimens show that the diffusion coefficients deduced for sodium (Na^{+}) and chloride (C^{-}) are directly related to the final bentonite void ratio.

Foose et al. (2001) developed analytical and numerical models to analyze leakage through composite landfill liners having various characteristics. Used Three-dimensional numerical models to analyze leakage through circular defects and to analyze leakage from defective seams used two-dimensional numerical models. The outcome of his comparisons show that existing equations and analytical models all have limitations and no universal equation or method is available for predicting leakage rates. To recover this problem he developed some new equation based on the results came from numerical models.

Bowman et al. (2001) worked on sustainable management of landfill leachate by irrigation they did a two year field experiment incorporating subsurface leachate irrigation of recreational turf was conducted at the Newington Landfill, Homebush Bay, Sydney. They concluded that the scheduling leachate irrigation in response to soil moisture, evaporation losses and rapid soil solution N analysis, enabled real-time low-cost control of N leaching losses and other thing is that the greatest limitation with the Newington leachate was its high salinity that adversely affected turf growth and soil structure when applied in undiluted state.

Foose et al. (2002) researched on three composite landfill liners. They compared in their study based on leakage rate, mass flux, and sorptive capacity. One composite liner consisted of a geomembrane and a geosynthetic clay liner. The other two had a geomembrane and a thicker soil barrier (61 or 122 cm). The analyses employed one- and three-dimensional numerical models that were developed for analyzing. They assumed contaminant transport through defects in the geomembrane component of composite liners and diffusion of volatile organic compounds through intact composite liners (i.e., composite liners without holes in the geomembrane).

Yeon-Soo Jang and Gyeong-Taek Hong (2003) applied diffusive characteristics of hardened liner materials (HLMs) to the liner system of Sudokwon Metropolitan Landfill in Korea. The laboratory pure diffusion column tests are performed by him in the pure- and the advection-diffusion status were performed for the chemicals, NaCl, KCl, and $CaCl_2$. As he analyzed the range of dispersion coefficients of advection diffusion column tests was a little narrower than that of diffusion coefficients of pure diffusion tests. In the literature work of him the diffusion coefficients of chloride ions consistent.

Datta (2003) presented the result of a study to know the effect of different factors like as landfill height as well as variations in liners and covers on the cost of making handling waste in municipal solid waste landfills and hazardous waste landfills. He concluded that the cost of per unit mass of waste material varies from Rs. 250 to Rs. 420 per ton for municipal waste and Rs. 420 to Rs. 620 per ton for hazardous waste. In the determination of cost landfill height has the most significant factor and variations in components of liners and covers can cause only a smaller change in landfilling cost.

Vasudevan et al. (2003) highlighted the landfill mining methods as phyto-remediation and in-situ treatments. He also emphasized some innovative uses and products being recovered from landfills, and put to use. He includes a case study on the Phytoremediation carried out by a common effluent treatment plant (CETP) nearby in Ranipet.

Stark et al. (2004) did Laboratory test and results and more recently field observations show that the thickness, or mass per unit area, of hydrated bentonite in a GCL can decrease under normal stress, especially around zones of stress concentration or non-uniform stresses, such as a rock or roughness in the sub-grade, a leachate sump, or wrinkles in an overlying geomembrane. They did the laboratory observations of bentonite migration and the effect of bentonite migration on hydraulic equivalence and contaminant transport through a GCL. Suggested for protecting hydrated bentonite from stress concentrations and reducing contaminant transport through a GCL

Smith et al. (2004) described the steady-state solution of a fully coupled set of transport equations modeling ion movement through a permanently charged platy-clay soil. Did micro scale analysis to takes into account the actual diffusion coefficient for each ion species, ion-pairing (as required by electroneutrality of the solution), as well as anion exclusion and cation inclusion, arising from the permanent charge on clay particles. To render the problem tractable, the theoretical analysis focuses on an extremely small two-dimensional unit cell in an ideal, saturated, two-phase porous medium.

Yong-gui et al. (2005) presented a hydrological model of water flow and a hydrodynamic model of contaminant to simulate the migration of leachate through clay-solidified grouting curtain in MSW landfills. He applied the model to simulate the sensitivity of the curtain's behavior to changes in parameters, such as thickness, depth, permeability coefficient, diffusion coefficient, resistance coefficient and concentration, and also to demonstrate the contaminant distribution on the evolution of travel time and offset distance of clay-solidified grouting curtain in landfills. The outcome of this modeling is that a part of leachate components stays or is retarded in clay-solidified grouting curtain by precipitate or exchange, the retention rate is closely related to composition of clay-solidified grouting curtain, more than 800/00, and the maximum occurs at the cement clay ratio of 2 : 4 under experimental conditions. His results indicates that clay solidified grouting curtain with a proper thickness, a low permeability coefficient and a high resistance coefficient might serve as a sufficiently effective vertical barrier against leachate seepage and contamination migration in MSW landfills.

B. V. S. Viswanadham and H. L. Jessberger (2005) applied in-flight simulation of non uniform settlements of landfill in a geotechnical centrifuge using a trap-door arrangement and explored the behavior of clay liner of landfills with and without reinforcement inclusion. The reinforcement ability of geosynthetic materials were used to control the crack propagation and permeability of clay liner even at large settlement differences. Their test results shown that a geogrid layer that is placed within the top portion of the clay liner restrains cracking and enhances the sealing efficiency due to soil–geogrid frictional resistance. The outcome of their study is the adoption of geosynthetic reinforced clay liner (GRCL) provides an ideal solution for enhancing the deformation capacity and the GRCLs are a promising barrier material for situations in which non uniform settlements are expected, for example, in landfill capping systems.

İ. Met and H. Akgün (2005) designed a landfill profile composed of a high density polyethylene (HDPE) geomembrane or clay composite liner through the Hydrologic Evaluation of Landfill Performance (HELP) model and the Water Balance Method on a attempt based. They assessed the geotechnical properties of the landfill layers along with the water balance factors to determine the height of the water saturated zone in the refuse above the composite liner for landfill design. They relate the cumulative expected leakage rates through the composite liner constructed with compacted Ankara clay and their result shows that leakage rates through the composite liner are within tolerable limits.

Craig B. Lake and R. Kerry Rowe (2005) analyzed the performance of 2.9 m thick compacted clay liner (CCL) for a landfill leachate lagoon for the migration of contaminants through it. They found that clay liner formed the lower portion of the composite liner system but the geomembrane (GM) have defects that had allowed leachate to migrate between the GM and CCL. They examined Chloride, sodium, potassium, calcium and magnesium pore water profiles through the CCL. It is found by them that chloride migrated approximately 1.7 m into the CCL during the 14 years of the lagoon operation, sodium approximately 1.2 m, and potassium 0.7 m. The importance of the compacted clay liner as part of the composite liner system is understood from this study, as it is acting as a diffusion barrier during the lifetime of the lagoon as well as using relatively non-conservative contaminants such as chloride and sodium to estimate the failure of geomembrane.

Marques et al. (2005) used sodium bentonite in the basal-isolation of landfills installed on strongly fractured granitic rocks of N Portugal (NW Iberia). They tested Nabentonite and done geophysical surveys to search for landfill leakage and the waters found around the landfill were geochemically characterized to find out mechanical and geotechnical behaviour of Nabentonite. They find that the fractures in the granite are usually open and devoid of mineral infillings or clay materials so the permeability of the granite is very high. According to them clay failed as an ultimate isolation barrier against seepage as geochemical data show evidence for seepage and dispersion of pollutants. It was due to fracturing of the clay under load and/or to its non-homogeneous saturation and extreme shrinking character upon drying, which are accompanid by the formation of extensive cracking. They suggested that the use of synthetic ‘‘clays’’ in the safe building of landfill bottom liners needs further research, and extreme care should be taken in preventing that clay water content suffers large variations after saturation.

Suman et al. (2006) examined the possible impact of leachate percolation on groundwater quality. They collected samples from Gazipur landfill site and its adjacent area. The results obtained that the moderately high concentration of EC, TDS, CL^-, SO_4^{2-}, NO_3^-, Na^+ and Fe etc. in groundwater near landfill deteriorates its quality for drinking and other domestic processes. The presence of Cl^-, NO_3^-, NH_4^+, Phenol and COD can be used as tracer with relation to leachate percolation. The ground water quality improves with the increase in depth and distance of the well from the pollution source.

Tsanis (2006) simulated a landfill site that contaminate an aquifer by leachate by using the groundwater flow and transport model SUTRA developed by the U.S. Geological Survey. He calibrate the model by spatially adjusting the hydraulic conductivity in order to capture the measured hydraulic head spatial variation and then by adjusting the dispersivity and porosity match the measured chloride plume. By the simulation he found that a pump-and-treat system using additional two purge wells could remediate the leachate contamination within approximately 10 years.

Rawas et al. (2006) investigated the potential use of sand–attapulgite (palygorskite) mixtures as a landfill liner. They brought sand and attapulgite clay from Wahiba (eastern Oman) and Al-Shuwamiyah (southern Oman) and determined the basic properties of the sand and clay and then attapulgite clay was added to the sand at 5, 10, 20 and 30% by dry weight of the sand. They analyses the sand attapulgite mixture in different methods. The results came out by the analysis by the X-ray diffraction attapulgite is the major clay mineral. Afterwards they determine chemical compounds, exchangeable cations and cation exchange capacity (CEC) for the samples. The geotechnical study conducted by them includes grain size distribution, Atterberg limits, specific gravity, compaction, hydraulic conductivity and shear strength tests showed that the sand + 30% clay mixture prepared at 2% above optimum water content can be considered to satisfy the requirements for landfill liners. They concluded that for all sand–clay mixtures no swelling was recorded and the addition of clay to the sand improved the shear strength.

Kartik et al. (2007) worked on phytocapping. It is an alternative technique to reduce leachate and methane generation from municipal landfills. It is considered as an effective, economic and environmental friendly technique for landfill remediation. In it, trees are established on a layer of soil cap placed over the refuse. The soil cover acts as a storage and tree act as bio-pump and filters. They choose a representative site for trial at Lakes Creek Landfill, Rockhampton, Queensland, Australia. they conclude that the plant established on thin layer are working as well as those growing in thick soil layer up to 1.5 years. The majority of them show no nutrient toxicity or deficiency symptoms.

B.V.S. Viswanadham, S. Rajesh, and S.S. Sengupta (2008) studied the behaviour of compacted clay barriers made-up of soil minerals of low permeability. They conclude that the differential settlements lead to bending and are critical for the behaviour of clay liners and that results loosening of integrity and sealing efficiency of clay barrier. To overcome this problem they suggested biaxial geogrid layer as an alternative solution for restraining cracking of clay barrier at the onset of differential settlements.

Bharat Jhamnani and S.K. Singh (2009) prepared five admixtures by using organoclay, natural soil, and bentonite in different amount and done laboratory experiments to identify the feasibility of them for use in landfill liner. The proportion of organiclay was 10 -25% and bentonite was 0-20% in the admixture. It is found by them that the admixture with higher percentage of organoclay exhibits higher organic sorption capacity. They determined the Retardation coefficient of the admixtures by curve fitting the experimental data of sorption tests to fit to Freundlich (nonlinear) sorption isotherm also performed one-dimensional transport simulations and evaluate the effectiveness of materials for use as landfill liner and to develop design charts for determining required liner thickness.

Hossam M. Abuel-Naga and Abdelmalek Bouazzab (2009) conducted numerical experiments to understand the effect of geometric and transport characteristics of a geomembrane(GM)- geosynthetic clay liner(GCL) composite liner on gas leakage rate through a circular defect in the geomembrane. They proposed a new conceptual two-layered system for modeling of GM/GCL composite liners where the interface zone between the GM and GCL has been merged with the GCL cover geotextile and handled as one layer and GCL bentonite layer was considered the second layer. The numerical simulation results show that the presence a constitutive leakage flow surface which enables evaluation of the leakage flow state for different geometric and transport properties of GM or GCL composite liners. It is understood by the study that the determined surface was also exploited to evaluate gas leakage rates under the framework of the Forchheimer's analytical solution.

Bharat Jhamnani and SK Singh (2009) analyzed the leachate coming from the Bhalaswa landfill site at New Delhi and the ground water contamination due to this. The leachate from Bhalaswa landfill was found to be having a high concentration of chlorides, as well as Dissolved Organic Carbon (DOC) and

COD. The generation rate is about 500 gm per person per day, which is almost 5 times the national average. The study determines concentrations of principle contaminants in the groundwater over a period of time due to the discharge contaminants from landfill leachates to the underlying groundwater. The result came out that the leachate from Bhalaswa landfill was found to be having a high concentration of chlorides, as well as DOC, COD. The observed concentration of chlorides in groundwater sample within 75m of Bhalaswa Landfill has been found to be 1174.2 mg/L. However, as the landfill facility is being continually progressing in height in absence of availability of a new landfill site, the total mass of chloride available for leaching is expected to increase, which may further increase the concentration of chloride in groundwater.

Bharat Jhamnani and SK Singh (2009) determined the rate of movement of potential contaminants from the bottom to the aquifer media; to do this they evolve a rational method for the determination of thickness of bottom barrier. The governing equation of contaminant transport was solved using finite difference method, and finite mass boundary condition. They used MatLab 7.0 for a range of Darcy velocities, and equivalent height of leachate to provide solution for the model. Design charts are drawn by them from the results of such simulation showing maximum relative concentration with depth at the end of simulation period over the domain of interest. These charts can be used can for determining the minimum thickness of barriers required at the bottom of landfill.

Rowe et al. (2010) examined a technique that controls the increase in landfill liner temperature due to the heat generated by the waste. Their design contains installation of an array of cooling pipes beneath the waste. They perform a series of analyses for conditions based on the Tokyo Port Landfill (Japan) to examine the feasibility of the system for cooling the liner. The result of their study signify that introduction of a cooling system can substantially reduce liner temperature and consequently significantly increase the service life of an HDPE geomembrane liner in an engineered barrier system. It is also signify by their study that the temperature of liner decreases with increased coolant transfer flow rate.

Sanjay et al. (2010) examined the pollution potential caused by the leachate produced by MSW dumped near the Pune, India and its impact on surrounding shallow basaltic aquifers. They determined twenty eight physico-chemical parameters during post and pre monsoon seasons to assess the seasonal variation in the leachate pollution index (LPI) as well as in the groundwater quality. After examine these parameters they concluded that the leachate derived from the Pune MSW dumping site shows very high values for almost all parameters. This high LPI value indicate that the leachate the leachate generated from dumping site are not stabilized, so resulting in high concentrations of heavy metals in leachate.

Rowe et al. (2010) described the accelerated aging tests to evaluate the depletion of antioxidants from a high density polyethylene. They examined the effects of temperature, high pressure, and continuous leachate circulation on the aging of geomembranes in composite liner systems. They found that the antioxidant depletion rates obtained for the simulated landfill liner at 250 Kpa vertical pressures are consistently lower than that obtained from traditional leachate immersion tests on the same geomembrane. By their test they conclude that the crystallinity and tensile yield strain of the geomembrane increased in the early stages of aging and then remained relatively constant over the testing period.

Khajuria et al. (2010) explained the correlation analysis of different factors of municipal solid waste in Asian. The Formulation is done by them to estimation of the future landfill area. And they concluded that the rapid urbanization and industrialization has caused tremendous increase of municipal solid waste generation in developing countries. They suggested 3R technologies should be used which helps to minimize the problems associated with the generation and safe disposal practices of municipal solid waste.

Ritwik Chakraborty and Ambarish Ghosh (2010) used Finite Difference Method to solve the one dimensional contaminant transport model to predict the pollutant migration through soil in waste landfill. In it they determined the velocity field first within a hydrologic system and these obtained velocities are used to calculate the rate of contaminant migration by solving the governing equation. They choose seven contaminants for analysis to represent a wide variety of wastes both organic and inorganic. By the use of these results they developed design charts for liners which are helpful for the designers.

CHAPTER 3
LANDFILL LINERS

3.1 INTRODUCTION:

At present landfills are engineered and optimise for handling solid waste disposal. They are designed in such a way to minimize the impact of solid waste (refuse, trash, and garbage) on the environment and human health. The waste is contained by a liner system in the modern landfills. The main use of the liner system is to differentiate the landfill contents from the environment and by doing so, protect the soil and ground water from pollution originating in the landfill.

The greatest indication or warning of probable trouble to ground water posed by modern landfills is leachate, consists of water and water-soluble compounds in the refuse and accumulate as water moves from the landfill. The migration of leachate may happen from the landfill and contaminate soil and ground water, hence because of this presenting a risk to human and environmental health. Because of this landfill liners are designed and constructed to work as a barrier between the waste and the environment and to drain the leachate to collection and treatment facilities. To prevent the uncontrolled release of leachate into the environment, this is done. In the society, different types of solid wastes are produced. That causes different threats to the environment and to community health. There are many factors which influence the production of leachate. One of which is climate condition of landfill site. As where the climate is prone more will be precipitation there will more water entering the landfill and the generation of leachate is more.

3.2 DIFFERENT LINER SYSTEMS:

To handle the solid wastes following types of liner systems are most commonly used in municipal solid waste single liner systems, composite liner systems and double liner systems.

3.2.1 Single Liner System:

The single liner system consists of a clay liner, a geosynthetic clay liner, or a geomembrane. These types of liners are commonly used to hold construction and demolition waste. Construction and demolition debris (C&DD) is nonhazardous, uncontaminated material resulting from construction, remodeling, repair, or demolition of different civil structures, and roads.

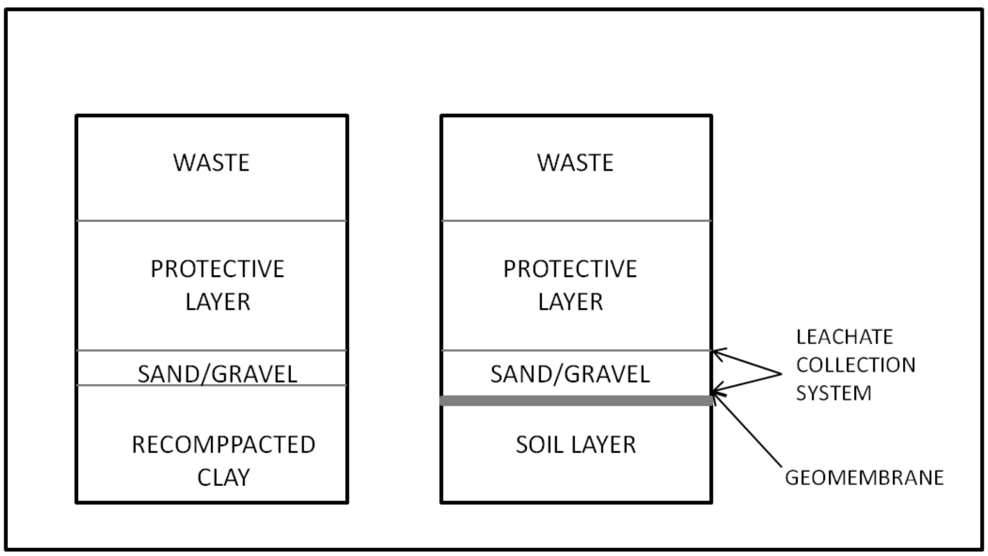


Fig. 3.1 Single Liner Systems Layout

Following materials are included in the C & DD (as per EPA):

i. Bricks, concrete, and other masonry materials
ii. Soil (mixed with other C&D debris)
iii. Rock
iv. Wood (nonhazardous painted, treated, and coated wood and wood products)

v. Wall coverings
vi. Plaster
vii. Drywall
viii. Plumbing fixtures
ix. Non-asbestos insulation
x. Roofing shingles and other roof coverings
xi. Reclaimed asphalt pavement
xii. Glass
xiii. Plastics (that do not conceal waste)
xiv. Electrical wiring and components (that do not contain hazardous substances)
xv. Piping
xvi. Metal materials (incidental to any of the materials above)

These landfills are not constructed to store paint, liquid tar, municipal garbage, or treated lumber. Therefore single-liner systems are usually adequate to protect the environment. It is cheaper to dispose of construction materials in a C&DD landfill than in a municipal solid waste landfill because C&DD landfills use only a single liner and are therefore cheaper to build and maintain than other landfills.

3.2.2 Composite-Liner Systems:

These liner systems are consists of geomembrane in combination with a clay liner. These are better effective for limiting leachate migration into the subsoil than either a clay liner or a single geomembrane layer.

There is a low-permeability, re-compacted clay soil. Over which high-density polyethelene (HDPE) secondary plastic liner is installed to cover the entire bottom and sides of the landfill cell. This plastic liner layer is chemically resistant to corrosion and damage. Both layers jointed together and tested to ensure a continuous seal in accordance with requirements. A blanket of geotextile fabric, i.e. composed of synthetic(felt-like fibers), is laid above the primary liner system, along with a geonet made of mesh-like plastic. At together, these composite liner systems prevent fine clay particles from clogging the leachate collection layer.

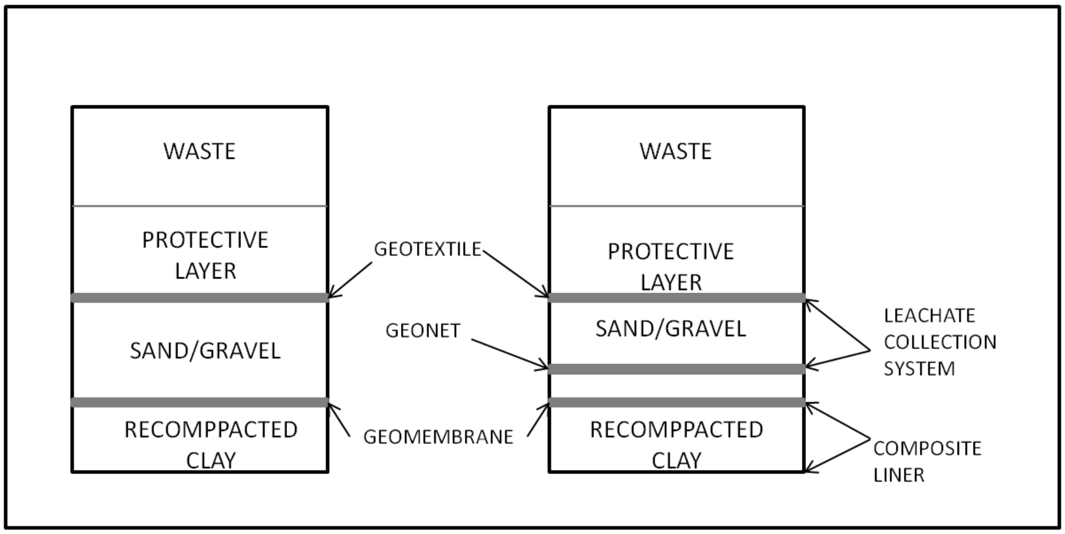


Fig. 3.2 Composite Liner Systems Layout

The solid waste that handled in composite liner systems are collected from residential, commercial, and industrial sources. These type of landfills also accept C&DD debris, but they don’t accept hazardous waste.

3.2.3 Double-Liner Systems:

The double liner system in made of may be of either two single liners and two composite liners or a single and a composite liner. The function of upper liner is to collect the leachate, and the lower (secondary) liner acts as a leak-detection system and backup to the primary liner. In it the primary leachate collection layer is a geonet or a granular layer. The primary one is a composite liner that consists of a geomembrane and a geosynthetic clay liner (GCL). The secondary collection layer of leachate made of a geonet and Geomembrane. This layer collects the leachate that leaks through the primary liner and conveys it by gravity to a collector swale. The collector typically contains multiple layers of geonet or a granular material and may contain a pipe. It conveys the leachate by gravity to a sump. The leachate is detected, measured and pumped in the sump.

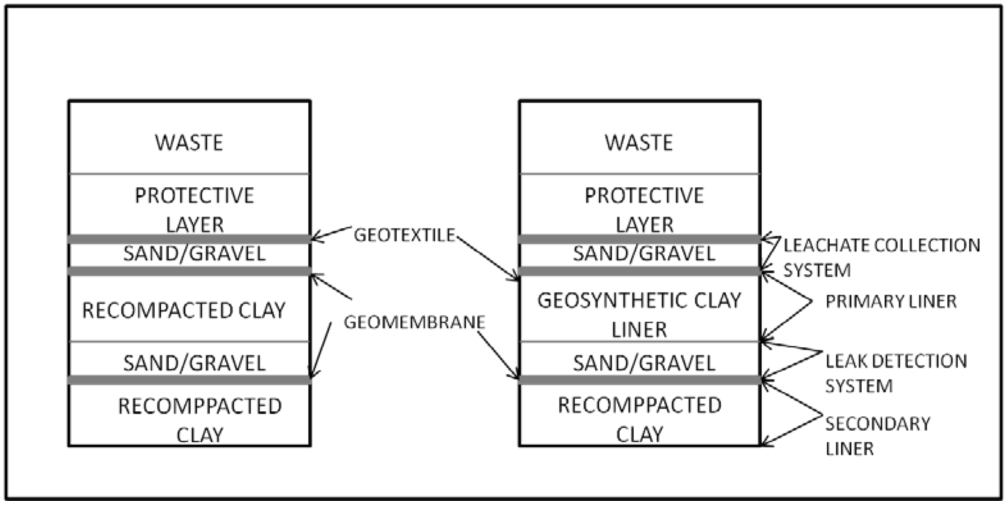


Fig. 3.3 Double Liner Systems Layout

These types of liner systems are used in some municipal solid waste landfills and in all hazardous waste landfills. Waste that poses substantial or potential threats to public health or the environment is called hazardous waste. Hazardous wastes classified into two major categories characteristic wastes and listed wastes as per the U.S. environmental laws (Resource Conservation and Recovery Act, RCRA). Characteristic hazardous wastes are those materials which are known or tested to show a hazardous property like toxicity, flammable, corrosive, reactivity. Second type is the listed hazardous wastes, which are materials that listed by the EPA (US Environmental Protection Agency) as a hazardous waste.

These listed wastes are again divided into two major categories:

(a) Process wastes from general activities and specific industrial processes.
(b) Unused or off-specification chemicals, container residues and spill cleanup residues of acute hazardous waste chemicals and other chemicals.

3.3 DIFFERENT TYPES OF LINER MATERIAL:

According to the property of solid waste and landfill site, different types of liner systems are used. In these liner system the materials those used as liner, can be broadly classified into two types, clay and geosynthetics.

3.3.1 Clay:

To protect the ground water from landfill contaminants, clay liners are constructed as simple liners which are two to five feet thick. The compacted clay layers are usually between two and five feet thick in composite and double liners. It depends on the characteristics of the underlying geology and the type of liner to be installed. It is specified by regulations that the clay used can only allow water to penetrate at a rate of less than 1.2 inches per year. In theoretical view one foot of clay is enough to contain the leachate. The additional clay is used to safeguard the environment in the event of some loss of effectiveness in part of the clay layer due to weathering. The clay liners efficiency can be maximized by putting the clay in four to six inch layers and then compact each layer with a heavy roller.

The efficiency of clay liners is reduced suddenly if they are keeping to dry out during placement. Extreme dryness of the clay during construction gives cracks that reduce the efficiency of liner. Additionally clays compacted at low moisture contents are not much effective barriers to contaminants than clays compacted at higher moisture contents. If we use Liners that made of a single type of clay are perform better than liners those constructed using several different types. The basic requirements of a compacted clay liner are that it should have permeability below a pre-specified limit and this should be maintained during the design life. The available natural clay in-situ is usually excavated and re-compacted in an engineered manner. If clay is brought from nearly areas, it is spread in thin layers and compacted over the existing soil. In certain areas, the quality of the in-situ clay may be good enough to exempt the requirement of a compacted clay liner.

At where the low-permeability clay is not available locally, the local soils can be mixed with medium to high plasticity imported clay or bentonite for gettinge the required low hydraulic conductivity. The admixtures of soil and bentonite are commonly used as low permeability amended soil liners.

Most high permeability soils can be blended with sodium bentonite to achieve hydraulic conductivity less than or equal to l x 10^{-7} cm/sec. Generally, well-graded soils require 5 to 10 percent by dry weight of bentonite, while uniformly graded soils (such as fine sand), may typically require 10 to 15 percent bentonite. The most commonly used bentonite admixture is sodium bentonite. Calcium bentonite may also be used, but more quantity of this bentonite may be needed to achieve the required k (coefficient of permeability), because it is more permeable than sodium bentonite. As a part of soil additive mix design, laboratory and field permeability tests as well as leachate compatibility tests should be performed to determine the amount and type of admixture required for a specific MSW.

An efficient liner made of compacted soil, clays or amended soils should fulfill the following requirements:

i. Hydraulic conductivity of 10^{-7} cm/sec or less.
ii. Thickness should be 100 cm or more.
iii. No presence of shrinkage cracks due to extreme dryness.
iv. Absence of lump of clay in the compacted clay layer.
v. Adequate strength for stability of liner under compressive loads as well as along side slopes.
vi. Minimal influence of leachate on hydraulic conductivity.

Clays of high plasticity with very low values of k, exhibit extensive shrinkage on drying, as well as tend to form large clods during compaction in the relatively dry state. Their permeability can also increase the entrance of certain organic leachates. Well compacted inorganic clays of medium plasticity, either natural or amended, appear to be most suitable for liner construction. In amended soils, the use of calcium betonies, in addition to sodium bentonite should also be examined to use as liner.

3.3.2 Geosynthetics Liner:

According to ASTM (American Society for Testing and Materials) geosynthetic has been defined as "a planar product manufactured from polymeric material used with soil, rock, earth, or other geotechnical engineering related material as an integral part of a man-made project, structure, or system." The geosynthetics that are routinely used in many forms are geotextiles, geogrids, geomembranes, erosion control blankets and mats, geosynthetic clay liners, geocomposite drainage materials and geonets. The analysis, design, installation and performance of geosynthetics employed in different fields are focus on specifications, design methodologies, construction techniques, long-term performance, and economics.

Though compacted clay liners have been invariably used but in a modern landfill system utilizes geosynthetics which gave an advantage to minimizing the possible long term adverse impact on the environment. Almost all types of geosynthetics could be of use in landfills. As the geosynthetics are factory manufactured polymeric materials which are typically produced in sheet form and seamed together in the field. Hence their built-in characteristics are thinness, light weight, good quality control, ease of installation, and general cost effectiveness are much better in comparison to natural soil materials. They also have the characteristics of being very unforgiving in their installation procedures thereby requiring constant vigilance by quality control during construction. Following are the typical types of geosynthetics commonly used in landfills:

Geosynthetic Clay Liner (GCL): Geosynthetic clay liners (GCLs) were first made in USA in 1980's. The demand for these products has grown after the consideration of GCL as cost effective alternatives to traditional compacted clay liners in vast applications. These types of liner materials are used in landfills (municipal and toxic), tailings facilities, mine waste residue impoundments and water reservoirs, water reservoirs applications. Many of GCLs are consist of a thin layer of sodium bentonite clay secured between two geotextiles. The primary function of which is to limit the migration of liquids.

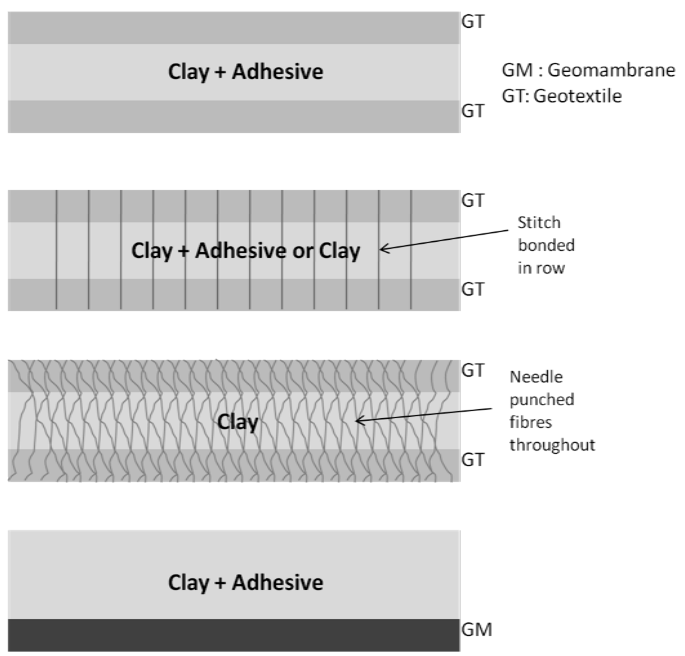


Fig. 3.4 Geosynthetic Clay Liners Cross Section

The rise of geosynthetic clay liners (GCL's) can be considered as a significant development as a replacement to traditional Compacted Clay Liner. It is considered in most cases as the first option when designing containment facilities or at the very least a comparable alternative to compacted clay liners.

Geotextile: It is a permeable synthetic textile product in the form of manufactured sheet, which may be woven, nonwoven or knitted and used in geotechnical, environmental, hydraulic and transportation engineering applications. Geotextiles are used to stop the movement of small soil and refuse particles into the leachate collection layers in landfill liners, and to protect geomembranes from punctures. These materials trap particles to reduce clogging in the leachate collection system and allow the movement of water. In corrent time geotextiles are usually made from, polyesters, polyamides, polyethylenes and synthetic polymers polypropylenes. Those do not decay under biological and chemical processes. This makes them more durable.

Geogrid: It is a synthetic structure, in the form of manufactured sheet that is consisting of a regular stable network of integrally connected elements, which may be linked by extrusion, bonding or interlacing. The openings of these are larger than the constituents, used in geotechnical, environmental, hydraulic and transportation engineering applications. Due to high tenacity (ultimate breaking strength of the fiber) used to reinforce retaining walls, steepened slopes and landfill liner systems. The geogrid provides excellent interaction with the surrounding soils allowing for efficient development of its tensile strength. Geogrids provide long term design strengths for construction of engineered reinforced soil structures.

Extruded geogrid: Polymer sheet that is punched and drawn in either one or two directions formed the extruded geogrids mat using a uniaxially or biaxially for improvement of engineering properties.

Bonded geogrid: The making of bonded geogrid is by bonding, usually at right angles, two or more sets of strands or other elements.

Geonet: It is a synthetic structure, in the form of manufactured sheet, consisting of a regular network of integrally connected overlapping ribs, which having openings usually larger than the constituents and used in geotechnical, environmental, hydraulic and transportation engineering applications.

Geospacer: It's a synthetic molded structure, consisting of corrugated plates (eventually perforated). It is used in geotechnical, environmental, hydraulic and transportation engineering applications.

Geomat: Geomat are made of three-dimensional water permeable polymer or other synthetic material which are thermally jointed with each other. They are used for fixing soil elements, grass and small plants roots, in geotechnical, hydraulic, environmental and other construction fields. Geomats are produced in form of regular or random oriented three-dimensional yarn structures. These are used to create stable vegetation along river, pond banks and slopes to keep away the erosion processes of surfaces. It is used in form of stereoscopic honeycomb constructions by combination with geotextiles to reinforce base and uplift the bearing resistance.

Geocell: Geocell consist of a regular open network of synthetic strips. It is a cellular structure and linked by extrusion, adhesion or other methods. They are often used to help improve the performance of erosion-control treatments and standard construction materials. It used in geotechnical, environmental, hydraulic and transportation engineering applications.

Geomembrane: Geomembranes are a kind of geosynthetic material that made up of impermeable or very low permeability membranes. These are made in the form of sheets. That may be plastomeric, elastomeric or bituminous. These are used commonly in geotechnical and environmental applications.

Geocomposite: As the name indicates, in geocomposite materials the combination of the best features of different materials is done in such a way that specific applications are addressed in the optimal manner and at minimum cost. Thus, the benefit/cost ratio is maximized. Such geocomposites will generally be geosynthetic materials, but not always. It can be used in geotechnical, environmental, hydraulic and transportation engineering applications for performing a specific function.

Geocomposite drain: It is an assembled structure of geosynthetic products, in the form of manufactured sheet or strip that is used in geotechnical, environmental, hydraulic and transportation engineering applications for performing drainage function.

Geocomposite reinforcement: This is an assembled structure of geosynthetic products, in the form of manufactured sheet, used in geotechnical, environmental, hydraulic and transportation engineering applications for performing reinforcement function.

Geocomposite membrane liner: This liner material is an assembled structure of geosynthetic products, in the form of manufactured sheet, consisting of at least one geomembrane among the components, used in geotechnical, environmental, hydraulic and transportation engineering applications for performing barrier function.

Biotextile: The latest and updated technology for textile industry where the enzymes are used in different process in order to achieve different goals is Bio-Textile. To carry out the enzymatic process living organism is used. The use of Bio textile is growing day by day in various industries. It is permeable textile material in the form of manufactured sheet, usually woven, used in geotechnical, environmental, hydraulic and transportation engineering applications.

Biomat*:* It is a black, slippery jelly-like structure. It is a very slowly permeable layer of partially decomposed organic waste containing microorganisms that seek to feed and growth of which done in this anaerobic environment. These are often found in any of following locations within a sewage disposal system at or on the bottom and sidewalls of the interface of aggregate soil. It consisting of a non-regular network of biodegradable natural fibers, yarns, filaments of other elements (generally mechanically connected), whose openings are usually larger than constituents. It used in geotechnical, environmental, hydraulic and transportation engineering applications.

Biocomposite and Biocomposite drain: A biocomposite is formed by a reinforcement of natural fibers and matrix. These are normally derived from plants or cellulose. It is having wide-range of uses from biodegradable composites to biomedical composites which are environment friendly and used for drug delivery, many applications of tissue engineering and cosmetic orthodontics. It can be used in geotechnical, environmental, hydraulic and transportation engineering applications, for performing a specific function while the later one performing drainage function by assembling it in the form sheet or strip.

3.4 COMPARISON OF GEOSYNTHETIC CLAY LINER (GCL) AND COMPACTED CLAY LINER (CCL):

Table 3.1 Comparisons of GCL and CCL

Characteristic	Geosynthetic Clay Liner	Compacted Clay Liner
Materials	Bentonite, Adhesives, Geotextiles and Geomembranes	Native Soils or Blend of Soil and Bentonite
Thickness	Approximately 12 mm; Consumes Very Little Landfill Volume	Typically 300 to 600 mm, Consumes More Landfill Volume
Hydraulic Conductivity	$\leq$ 1 to 5 x 10^{-11} m/s	$\leq$ 1 x 10^{-9} m/s
Speed and Ease of Construction	Rapid, Simple Installation	Slow, Complicated Construction
Ease of Quality Assurance (QA)	Relatively Simple, Straight Forward Common-Sense Procedures	Complex QA Procedures Requiring Highly Skilled and Knowledgeable People
Vulnerability to Damage During Construction from Desiccation and Freeze-Thaw	GCLs are Essentially Dry; GCLs Cannot Desiccate during Construction; Not Particularly Vulnerable to Damage from Freeze-Thaw	Compacted Clay Liners Are Nearly Saturated; Can Desiccate during Construction; Vulnerable to Damage from Freeze-Thaw
Vulnerability to Damagefrom Puncture	Thin GCL is Vulnerable to Puncture	Thick Compacted Clay Liner Cannot Be Punctured Accidentally
Vulnerability to Damage from Differential Settlement	Can Withstand Much Greater Differential Settlement than Compacted Clay Liner	Cannot Withstand Much Differential Settlement Without Cracking
Availabilty of Materials	Materials Easily Shipped to Any Site	Suitable Materials Not Available at All Sites
Cost	Reasonably Low, Highly Predictable Cost that Does Not Vary Much from Project to Project	Highly Variable – Depends Greatly on Characteristics of Locally Available Soils _.
Ease of Repair	Easy to Repair with Patch Placed Over Problem Area	Very Difficult to Repair, Must Mobilize Heavy Earth-Moving Equipment
Experience	Limited Due to Newness	Has Been Used for Many Years

Source: Landfill liners: Use of Geosynthetics by ***G. Venkatappa Rao***

CHAPTER 4
PERFORMANCE OF LANDFILL LINER MATERIALS ON THE MIGRATION OF CONTAMINANT

4.1 INTRODUCTION

The transport of solutes is done in porous media by two basic processes: diffusion and advection. These two process control the transport of solutes. In the Diffusion process solute moves from areas of higher chemical potentials to areas of lower chemical potentials. This process is also known as molecular diffusion. In the Advection process dissolved solutes are carried along with the flowing fluid mass.

The mathematical approach to do DEFINE both advection and dispersion is advection-dispersion equation. The advection-dispersion equation is the basic relationship that is used to describe mass transport in porous media. The advection-dispersion equation having applications in the problems involving chemical spills, contaminant plumes, and mass transport through aquifers are described. The mass transport by bulk fluid movement caused by fluid energy gradients and mixing of chemical constituents caused by the presence of concentration gradients and random molecular motions is described by Advection and diffusion respectively. Advection is the basic transport mechanism associated with bulk movement i.e. the transport of a chemical species as it moves along with the fluid flow.

The transport associated with the average bulk fluid movement is called advective transport. The mechanical dispersion is the transport associated with deviations from the average. On top of these two processes, diffusion still operates. So that the advection-dispersion includes the processes of advection, mechanical dispersion, and diffusion. The latter two processes are often grouped as hydrodynamic dispersion (or hydrodynamic dispersion tensor).

4.2. GUIDELINES AND MATHEMATICAL MODELING:

The contaminant migration mechanism evolution and the ability to reduce contaminant migration through barrier materials are important to prevent the contamination of soil and groundwater under landfills. For clay liners, which have a very low hydraulic conductivity with a low hydraulic head, a contaminant will be slowly transported and is controlled by diffusion through the clay pore fluid. It is often believed to be the primary barrier to contaminant transport is geomembrane. Yet, for volatile organic compounds the clay component usually controls the rate of transport since volatile organic compounds. Additionally, the transport of volatile organic compounds is more critical than transport of inorganic compounds even though volatile organic compounds are often found at lower concentrations in leachates.

To take proper control of contaminant migration, and for feasible optimum performance, the composite liners are preferably used in place of Compacted Clay liner. Composite liner consists of, two or more components, a geomembrane and a low-permeability soil layer. The geomembrane component is placed on top of the low-permeability soil layer, that decreases percolation of leachate into the liner and helps in lateral flow of leachate in the leachate collection layer overlying the composite liner because the geomembrane is less permeable than the low-permeability soil. For hazardous waste double liner is used. By the leachate collections layer the leachate collection and removal is maximized and percolation of leachate into the liner is minimized.

The comparison of landfill liners in done between following liner materials:

i. Compacted Clay (CCL)
ii. Geosynthetics Clay (GCL)
iii. Geomembrane

The advection dispersion equation, of single degree and second order partial differential equation, of parabolic type is solved. The analytical method is used to solve this model. This technique is well suited for complex geometries, complicated flow patterns, heterogeneity and nonlinearity. Then the simulation work for one dimensional contaminant migration is done by using MATLAB. The solute is assumed as a conservative solute, (Like an ideal tracer) which is a substance that moves through a porous medium without interacting with the matrix or undergoing chemical or biotic transformations. This simulation describes the concentration of the contaminant at different time and at various depth of the liner.

The performances of three liner materials, compared in the study, are majorly used in all forms of liner systems (i.e. single, composite and double). On the basis of their Effective Porosity, Tortuosity and Effective Molecular Diffusion Coefficient, these three are studied and their behavior is analyzed. The values of these different parameters are shown in table 4.1. efective Porosity and tortuosity value of Compacted Clay Liner and Geosynthetics Clay liner taken from Stark et al. (2003) and of Geomembrane from Shackelford and Daniel (1991b) and Shackelford (1989). Effective molecular diffusion coefficient of Compacted Clay Liner, Geosynthetics Clay liner and Geomembrane taken from Smith et al. (2004), Rowe et al. (2000) and Parks and Nibras.

The following assumptions are considered in the analysis:

i. The liners are assumed to be homogeneous and saturated.
ii. The transport of the pollutant is assumed vertically downward from the landfill towards the groundwater system.
iii. The length and width of the landfill are considerably large to the thickness of the clay liner and therefore, one dimensional flow of the governing equation is applied.
iv. Second order one-dimensional form of the advection-dispersion equation for non reactive solute transport in saturated porous media is considered.
v. The solute is assumed a conservative solute (as an ideal tracer).

vi. The contaminant flow is in steady state and Darcy's law is valid.

It is assumed that the inlet concentration is constant (i.e. Dirichlet or type one boundary condition). Following values of Effective Porosity, Tortuosity and Effective Molecular Diffusion Coefficient are used as input value for the analysis purpose.

Table: 4.1 Effective Porosity, Tortuosity and Effective Molecular Diffusion Coefficient values used of CCL, GCL and Geomembrane

Liner Material	Effective Porosity (n_e) (no UNIT)	Tortuosity (τ) (no UNIT)	Effective Molecular Diffusion Coefficient (D_{eff}) (m^2/day)
Compacted Clay Liner	0.37	0.10	6.91×10^{-5}
Geosynthetics Clay liner	0.66	0.34	1.98×10^{-5}
Geomembrane	0.54	0.24	2.59×10^{-8}

The three dimensional form of advection-dispersion equation is following:

$$R\frac{\partial C}{\partial t} = \Delta.(D.\Delta C) - \Delta.(vC) \ldots\ldots\ldots\ldots (1)$$ (***Randall, 2000)***

Where, C = concentration of solute;

t = time;

D = hydrodynamic dispersion tensor;

v = seepage velocity; and

R = retardation factor,

Retardation factor R can be defined as:

$$R = 1 + \frac{\rho_d K_d}{n} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.\ldots..(2)$$ ***(Randall, 2000)***

Where, ρ_d = dry unit weight of soil;

K_d = partition coefficient; and

n = porosity

For the 1-dimensional advection dispersion equation (ADE) for uniform velocity, porosity, and dispersion coefficients, the equation (1) reduces to

$$\frac{\partial C}{\partial t} + v_x \frac{\partial C}{\partial x} - D_x \frac{\partial^2 C}{\partial x^2} = 0 \;\ldots\ldots\ldots\ldots\ldots..(3)$$ ***(Randall, 2000)***

A MATLAB program is made to solve advection dispersion equation of 1-D Semi-Infinite depth for analyzing the solute transport in different liner materials.

The concentration ratio $\frac{C(x,t)}{C_0}$ gives the concentration at particular depth with respect to initial concentration. This can be found analytically by following analytic function:

$$\frac{C(x,t)}{C_0} = erfc\left(\frac{x}{2\sqrt{D^* t}}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.(4)$$

Eq. 4 is the main governing equation in this modeling work. The *'erfc'*, in eq. 4, is a complementary error function, called Gauss error function. The concentration of solute in this modeling work, at different depth and after different time periods, in liner materials, is calculated by using equation 4. The values of effective porosity, tortuosity, effective molecular diffusion coefficient (table 4.1) of different liner materials used in calculation. The depth of liner material is considered as semi infinite. A MATLAB program is made to find out concentration ratio $\frac{C(x,t)}{C_0}$ at different depth and after different time interval.

On the Basis of results different graphs are plotted between concentration ratio $\frac{C(x,t)}{C_0}$ and depth of landfill liner materials after time interval 0.5 years, 10 years and 50 years.

CHAPTER 5
RESULTS AND DISCUSSIONS

The analysis of different landfill liner materials Compacted Clay liner, Geosynthetics Clay liner and Geomembrane done by using MATLAB program provide significant results. Consider C_0 is the concentration of solute at initial boundary or we can say at the surface of liner and C is the concentration at particular liner depth 'x'. Then find out the concentration ratio (C/C_0) at different depth of liner.

On the basis of analysis graphs are plotted (fig 5.1, 5.2, 5.3, 5.4, 5.5 and 5.6) between C/C_0 (concentration ratio), and the liner depth (x), at different time interval of 0.5 years, 10 years and 50 years for Compacted Clay Liner, Geosynthetics Clay Liner and Geomembrane Liner. In the first three graphs identical graph is made for different depth conditions and in the next three graphs the depth is fixed to 0.0035m for all liner materials. A data sheet is made which represents the concentration of solute a different depth of liner the material.

Following inference comes out after the analysis of data and graphs:

i. In all three materials as we go from upper to bottom part of liner, the concentration ratio (C/C_0) decreases. So it can also be said that for Compacted Clay Liner, Geosynthetics Clay Liner and Geomembrane Liner the concentration (C) of solute reduces as we go at more and more depth.

ii. The decrease in concentration ratio with depth is much higher 10-100 times for time duration 0.5 years, 10 years and 50 years in Geomembrane than Compacted Clay Liner, Geosynthetics Clay Liner.

iii. For compare Compacted Clay Liner and Geosynthetics Clay the performance of Geosynthetics Clay liner is better as the decrease in concentration ratio is about 3 times then the Compacted Clay Liner.

The time duration also put a significant impact. The curves drown after three time intervals 0.5 years, 10 years and 50 years. At different time intervals the gradient of graphs decreases significantly for 0.5 years, 10 years and 50 years.

5.1 VARIATION OF SOLUTE CONCENTRATION WITH TIME IN COMPACTED CLAY LINER:

i. At the age of half year the concentration ratio reduced rapidly with depth and become nearly zero at about 0.003 m depth.
ii. At the age of 10 years the change in concentration ratio is not so drastically and reduced with depth and become nearly zero at about 0.012 m depth.
iii. For the duration of 50 years the change in concentration ratio very slowly and reduced with depth and become nearly zero at about 0.028 m depth.

5.2 VARIATION OF SOLUTE CONCENTRATION WITH TIME IN GEOSYNTHETICS CLAY LINER:

i. At the age of half year the concentration ratio reduced rapidly with depth and become nearly zero at about 0.08 m depth.
ii. At the age of 10 years the change in concentration ratio is not so drastically and reduced with depth and become nearly zero at about 0.038 m depth.
iii. For the duration of 50 years the change in concentration ratio very slowly and reduced with depth and become nearly zero at about 0.088 m depth.

5.3 VARIATION OF SOLUTE CONCENTRATION WITH TIME IN GEOMEMBRANE:

i. At the age of half year the concentration ratio reduced rapidly with depth and become nearly zero at about 0.00025 m depth.

ii. At the age of 10 years the change in concentration ratio is not so drastically and reduced with depth and become nearly zero at about 0.0012 m depth.

iii. For the duration of 50 years the change in concentration ratio very slowly and reduced with depth and become nearly zero at about 0.0027 m depth.

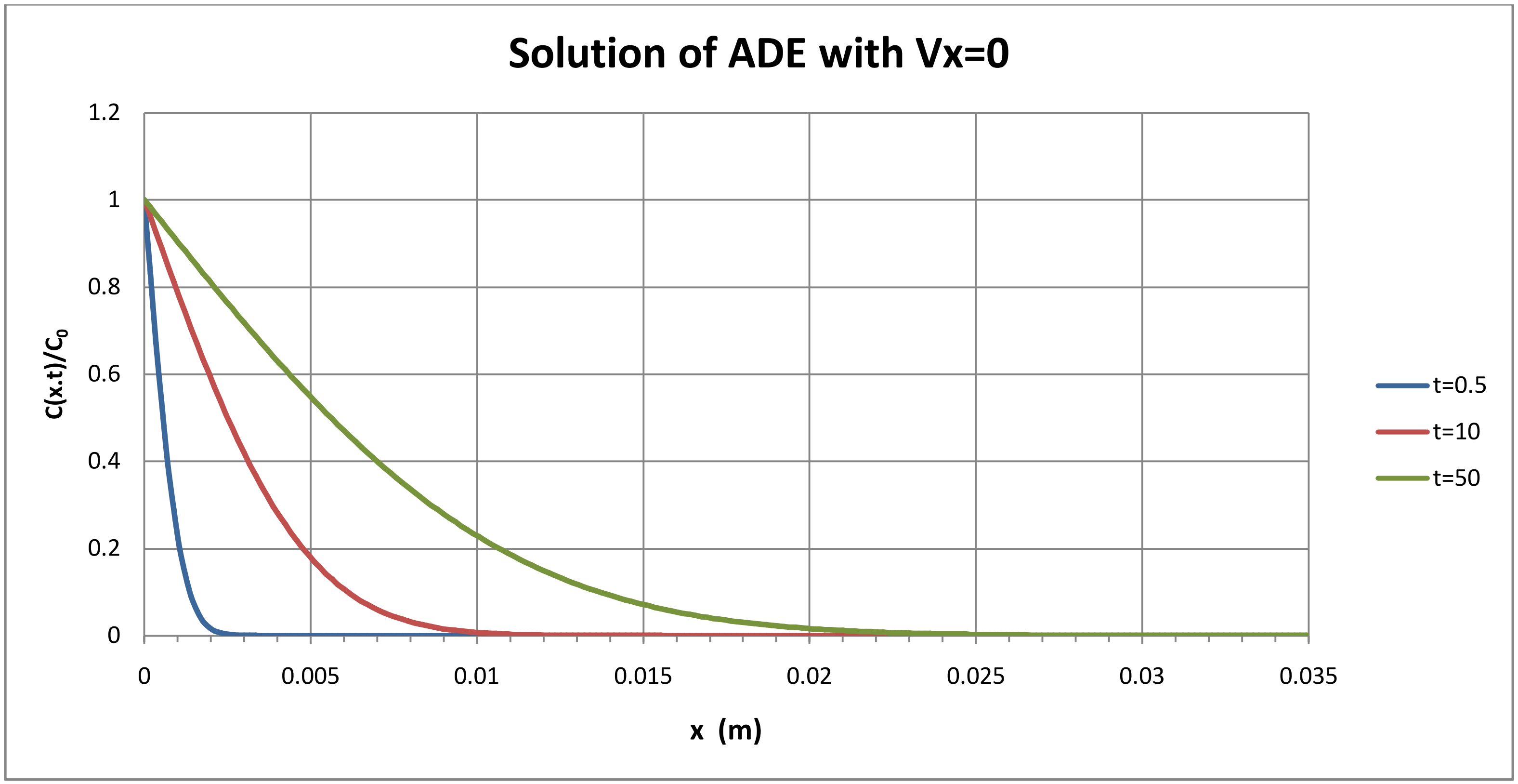


Fig. 5.1 Compacted Clay Liner Behavior in Solute Transfer

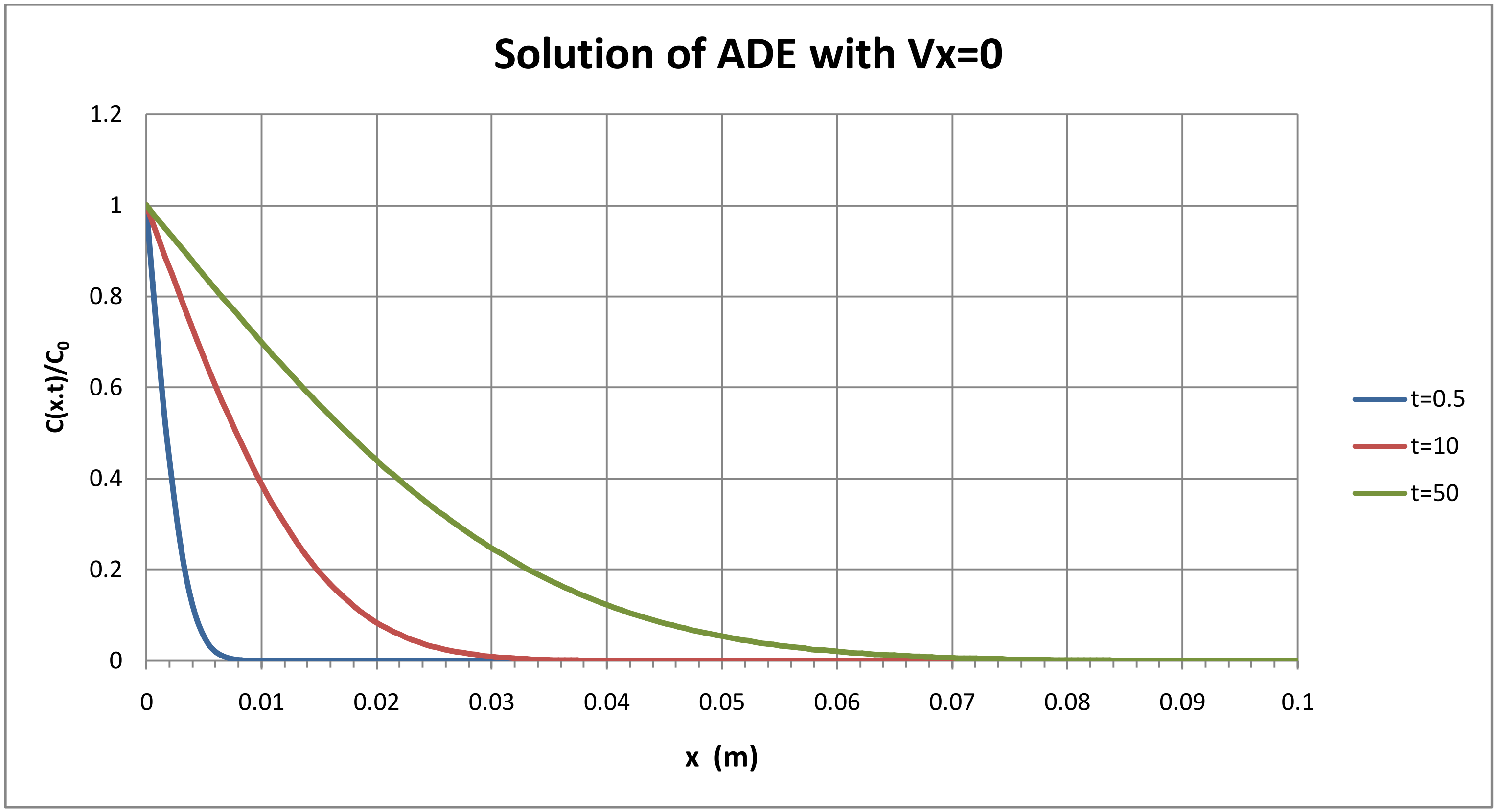


Fig. 5.2 Geosynthetic Clay Liner Behavior in Solute Transfer

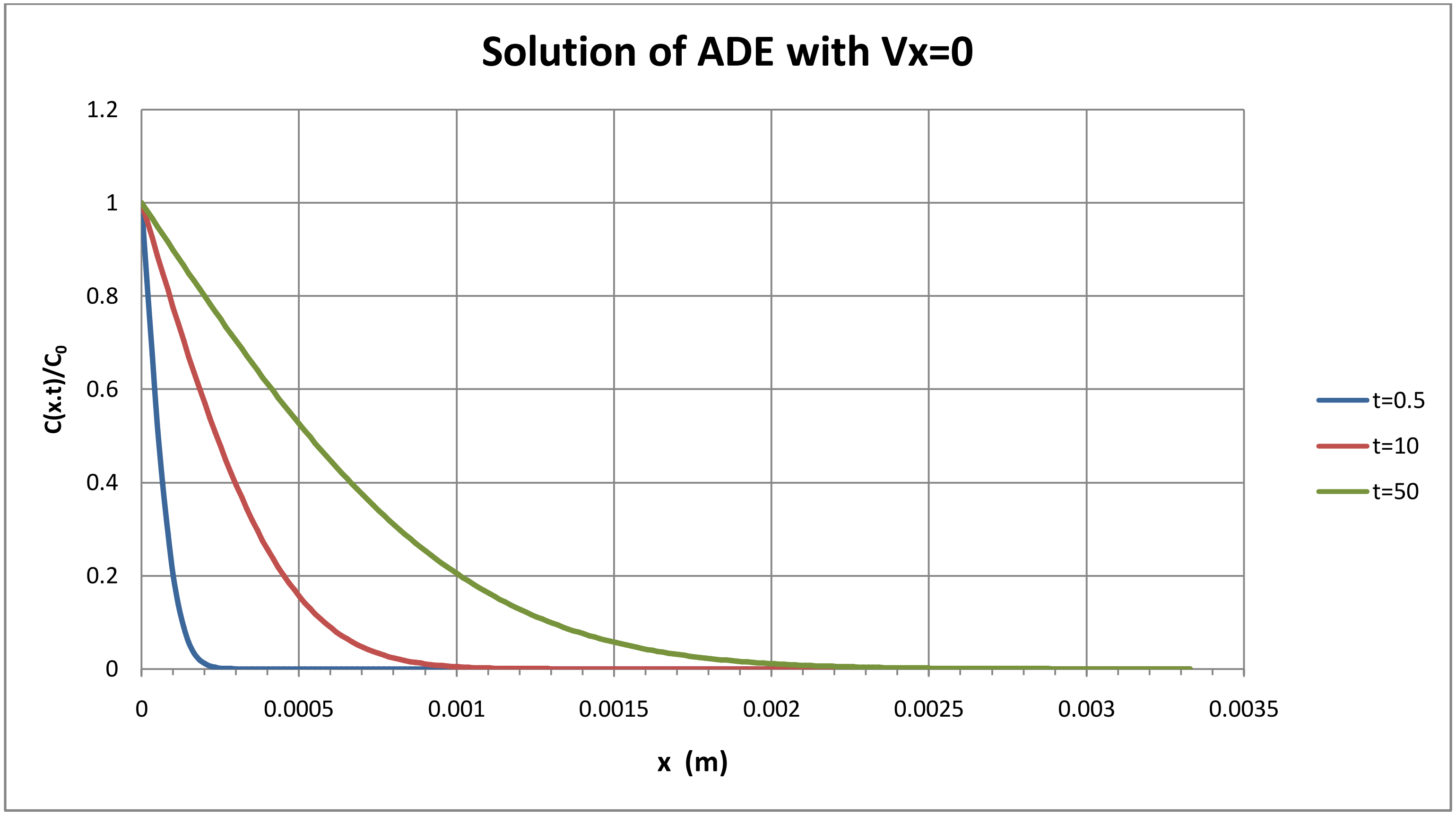


Fig. 5.3 Geomembrane Clay Liner Behavior in Solute Transfer

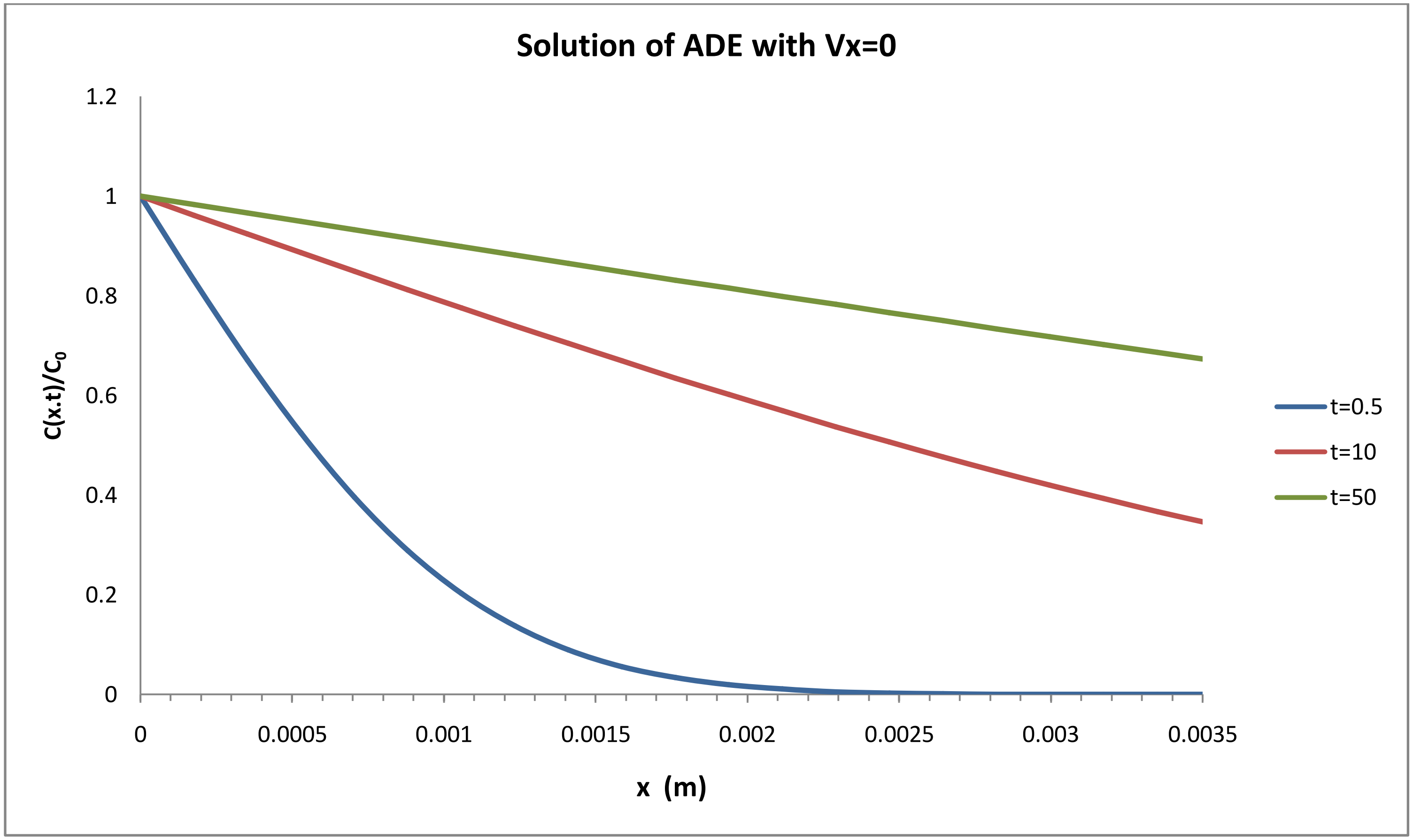


Fig. 5.4 Compacted Clay Liner Behavior in Solute Transfer up to depth 0.0035m

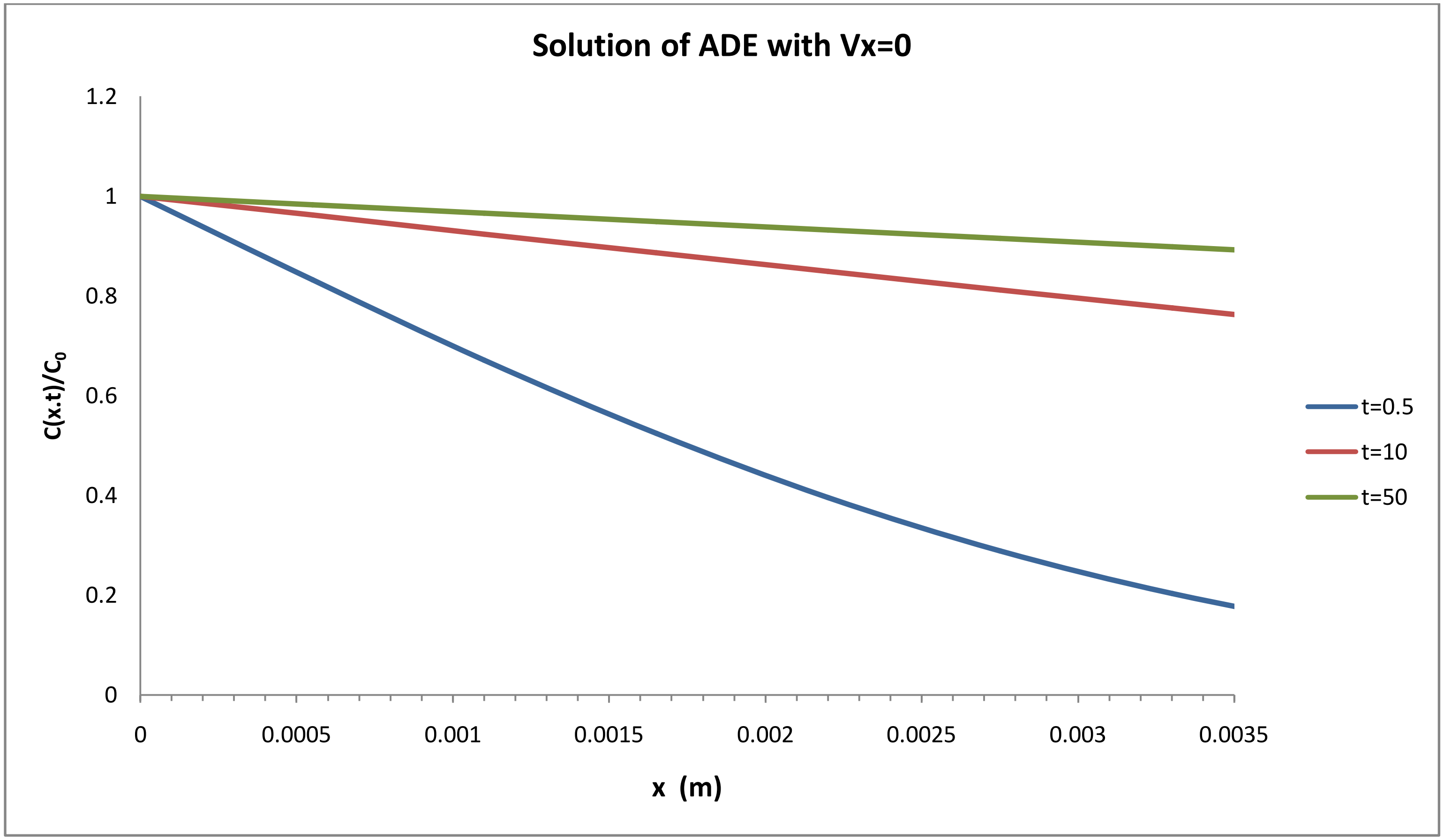


Fig. 5.5 Geosynthetic Clay Liner Behavior in Solute Transfer up to depth 0.0035m

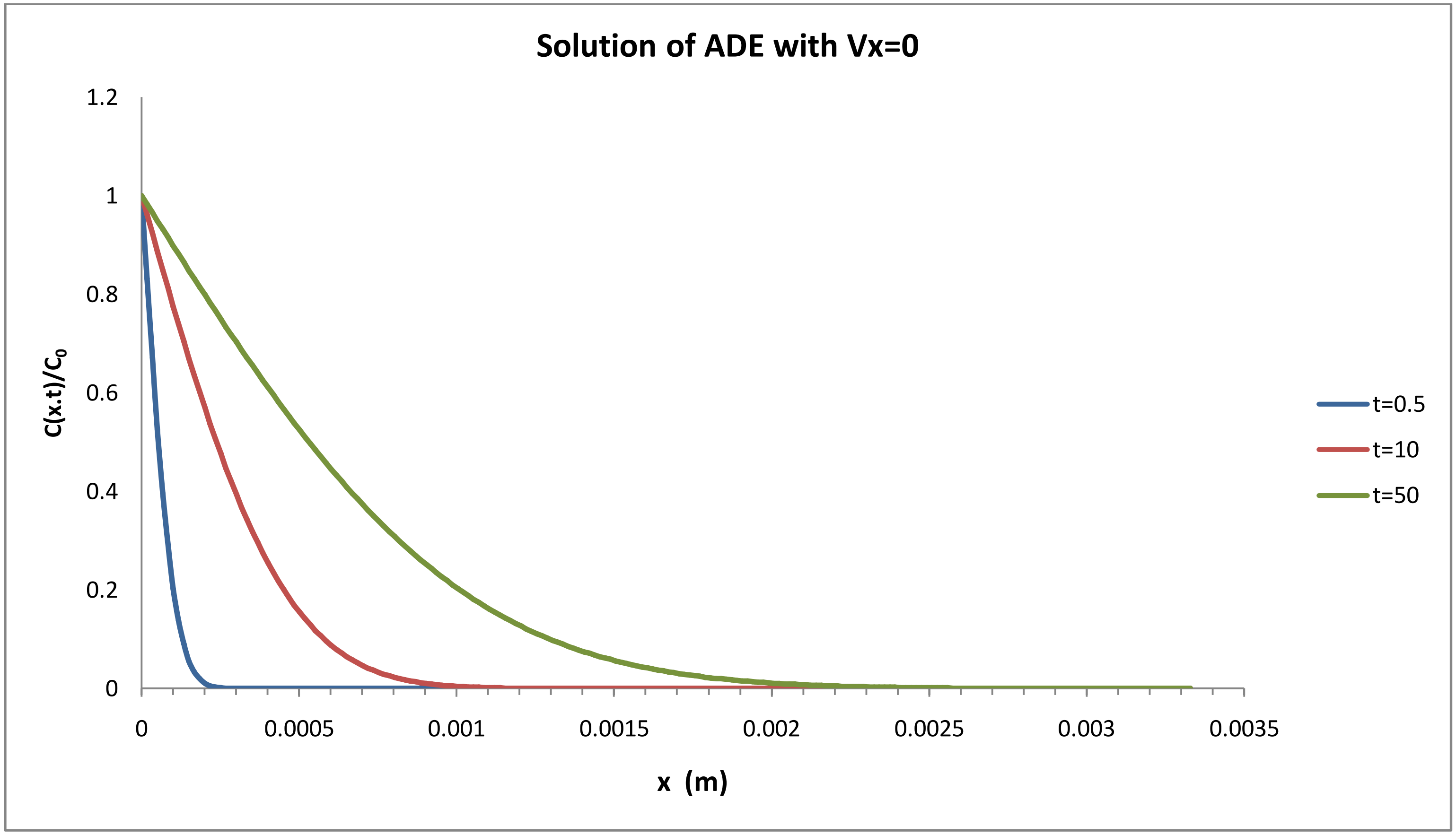


Fig. 5.6 Geomembrane Clay Liner Behavior in Solute Transfer up to depth 0.0035m

CHAPTER 6
CONCLUSIONS AND RECOMMENDATIONS

As wastes are manly arising from human and animal activities and which are found in solid or semi solid form we called solid waste. The methods used for the management of the solid waste are land-filling, composting, windrow composting, incineration and recycling. To trap the path of leachate that migrate through soil strata and contaminate the ground water land-filling method is used. At present landfills are engineered and optimise for handling solid waste disposal. They are designed in such a way to minimize the impact of solid waste (refuse, trash, and garbage) on the environment and human health. The greatest indication or warning of probable trouble to ground water posed by modern landfills is leachate which consists of water and water-soluble compounds in the refuse and which accumulate as water moves from the landfill. So the landfill liners are designed and constructed to work as a barrier between the waste and the environment and to drain the leachate to collection and treatment facilities. To handle the solid wastes single liner systems, composite liner systems, double liner systems are liner systems which are most commonly used in municipal solid waste. The three principal materials used in landfill liner systems are Compacted Clay, Geosynthetics Clay and Geo Membrane.

The two process controls the transport of solutes are advection and dispersion. Mathematical approach to do define both advection and dispersion is single degree and second order partial differential equation. It is a basic relationship that is used to describe mass transport in any porous media. Three liner materials, compared in the study, are majorly used in all forms of liner systems (i.e. single, composite and double). These are following Compacted Clay, Geosynthetics Clay and Geo Membrane. The properties used as an input data are their effective porosity, tortuosity and effective molecular diffusion coefficient, these three are studied and their behavior is analyzed.

Following are the conclusions of study:

i. The thickness of Compacted Clay Liner is typically in the range of 300 to 600 mm and the thickness of Geosynthetics Clay Liner is approximately 12 mm. So Geosynthetics Clay Liner consumes very little land fill volume compare to Compacted Clay Liner.

ii. The cost of Compacted Clay Liner is highly variable and depends mainly on characteristics of locally available soils, whereas the cost of Geosynthetics Clay Liner and Geomembrane is reasonably low and highly predictable.

iii. Compacted Clay Liners are difficult to repair if they are damaged must need of heavy earth moving equipment but the Geosynthetics Clay Liners are easy to repair with patch placed over problem area.

iv. The hydraulic conductivity of Compacted Clay Liner is higher (about 100 times) than the Geosynthetics Clay Liner and Geomembrane.

v. The transport of solutes in different liner material is governed by two basic processes diffusion and advection.

vi. The decrease in concentration ratio with depth is much higher (about 1000 times) in Geomembrane than other two.

vii. Decrease in concentration ratio is about 3 times more in Geosynthetics Clay Liner than the Compacted Clay Liner.

viii. In all the three liner materials the decrease in concentration ratio reduces gradually with time.

These conclusions have some limitations as it is not based on laboratory or field data regarding contaminant transport from landfill liner materials. So the accuracy of this model for replicating field conditions is unknown. These conclusions are fully based on solute transport mechanism. At here the other factors like resistance to environmental degradation potential for catastrophic puncture, construction quality, and mechanical stability are not considered.

6.1 RECOMMENDATIONS:

In India where is engineered disposal of MSW is just in a growing faze. Surat, Pune, AUPA (Gujrat), Ajmedabad, Puttar, Karwar and Navi Mumbai are some places where engineered landfill system is available. Even the capital of India is waiting for its first engineered landfill site. With the three existing landfill sites oversaturated in delhi, the Municipal Corporation of Delhi (MCD) is set to make its new Narela-Bawana landfill site operational, according to a report in The Times of India (TOI). The Narela-Bawana site is said to be the first engineered landfill site in the Delhi, India, and will segregate and process close to 1300 metric tonnes of solid waste each day, producing refuse derived fuel (RDF) for industrial use, compost and recyclable material with only 25% being landfilled, from the latest TOI (28/6/2011) "Narela-Bawana landfill site to be operational next week".

In the present scenario where the engineered landfill for a small town or village is not feasible in India as many big cities are waiting for it. Compacted Clay Liner suggested liner material for small town and village because it required very less skilled supervision, and the repairing and maintenance of it is easy compared to Geomembrane and Geosynthetics Clay Liner. But for the big cities where the availability of skilled technical person is not a problem the Compacted Clay Liner should be avoided and Geosynthetics Clay Liner preferred over it. As it consume very little landfill volume, less hydraulic conductivity, Ease of Quality assurance, reasonably low and highly predictable cost, also simple and rapid installation.

Following are the recommendation of the study:

i. Compacted Clay Liner can be used in the areas where there is a lack of skilled supervision, also the repair and maintenance of it is easy.

ii. In urban areas Geosynthetics Clay Liner should be preferred over Compacted Clay Liner, if skilled manpower is available for its installation. It is likely to provide the performance better than that of CCL with even lesser depths, resulting onto saving of costly space in urban areas..

iii. In industrial zone where much care is needed in landfill liner geomembrane with Geosynthetics Clay Liner can be used to handle hazardous waste.

6.2 SCOPE FOR FURTHER RESEARCH:

i. The time duration used in this study can be further increased to 100 or 150 years.

ii. Study can be enhanced to three dimensional solute transport models which will give further more accurate solutions.

iii. More specific material can be used for study.

REFERENCES

1. Alexander C. Demetracopoulos, A. M. ASCE and Lily Sehayek -***"Design Considerations for a Novel Landfill Liner"***. Journal of Environmental Engineering,Vol. 111, No. 4, 528-539, August, ASCE (1985).

2. Craig H. Benson - ***"Probability Distributions for Hydraulic Conductivity of Compacted Soil Liners"***. Journal of Geotechnical Engineering, Vol. 119, No. 3,471-486, March, ASCE (1993).

3. Bruce M. McEnroe - ***"Maximum Saturated Depth over Landfill Liner".*** Journal of Environmental Engineering, Vol. 119, No. 2, March/April, 262-270, ASCE (1993).

4. Park, J. K., and Nibras, M. - ***''Mass flux of organic chemicals through polyethylene geomembranes''*** *Water Environ. Res.*, 65(3) 227–237. (1993)

5. Rowe, R. K., and Booker, J. R. - ***''POLLUTE v6.3-1D pollutant migration through a nonhomogeneous soil''***. distributed by GAEA Environmental Engineering, Ltd. (1997)

6. Kim, J. Y., Edil, T. B., and Park, J. K. - ***''Effective porosity and seepage velocity in column tests on compacted clay''***. *J. Geotech. Geoenviron. Eng.*, 123(12), 1135–1142. (1997)

7. Mariusz Kaczmarek and Tomasz Huckel – ***"Chemo-Mechanical Consolidation of Clays: Analytical Solutions for a Linearized One-Dimensional Problem"***. Transport in Porous Media 32**:** 49–74, Kluwer Academic Publishers (1998).

8. Loretta Y. Li and Guangxi Wu – ***"Numerical Simulation of Transport of Four Heavy Metals in Kaolinite Clay"***. ***Journal of Environmental Engineering***, Vol. 125, No. 4, 314-324, April, ASCE (1999).

9. Despina Fatta, Achilleas Papadopoulos and Maria Loizidou – ***"A Study on the Landfill Leachate and Its Impact on the Groundwater Quality of the Greater Area".*** Environmental Geochemistry and Health 21: 175–190, ***S****pringer link* (1999).

10. R. Kerry Rowe, Craig B. Lake, and Robert J. Petrov – ***"Apparatus and Procedures for Assessing Inorganic Diffusion Coefficients for Geosynthetic Clay Liners"***. Geotechnical Testing Journal, GTJODJ, Vol. 23, no. 2, June, pp. 206–214, (2000).

11. Gary J. Foose, Craig H. Benson, and Tuncer B. Edil – ***"Predicting Leakage Through Composite Landfill liners"***. Journal of Geotechnical and Geo-environmental Engineering, Vol. 127, No. 6, 510-520, June, ASCE (2001).

12. Mark S. Bowman, Timothy S. Clune and Bruce G. Sutton – ***"Sustainable Management of Landfill Leachate By Irrigation".*** *Water, Air, and Soil Pollution 134: 81–96, 2002. Springer link* (2001).

13. Gary J. Foose, Craig H. Benson, and Tuncer B. Edil – ***"Comparison of Solute Transport in Three Composite Liners"***. Journal of Geotechnical and Geoenvironmental
Engineering, Vol. 128, No. 5, 391-403 May 1, ASCE (2002).

14. Yeon-Soo Jang and Gyeong-Taek Hong – ***"An Experimental Study on Diffusion Characteristics of Hardened Liner Materials to Inorganic Chemicals"***. Journal of Environmental Geology, 44:599–607, Springer-Verlag (2003).

15. Manoj Datta – ***"Factors which Influence the Cost of MSW and HW Landfills"***. Workshop on Sustainable Landfill Management 3–5 December, pp. 239-243, Chennai (2003).

16. Naveen K. Vasudevan, S. Vedachalam and Dheepak Sridhar – ***"Study on the Various Methods of Landfill Remediation"***. Workshop on Sustainable Landfill Management 3–5 December, pp. 309-315, Chennai (2003).

17. T. D. Stark, H. Choi and R. Akhtarshad – ***"Occurrence and effect of bentonite migration in geosynthetic clay liners"***. Geosynthetics International, 11, No. 4, 296-310, Thomas Telford Ltd (2004).

18. David Smith, Peter Pivonka1, Christian Jungnickel and Stephen Fityus – ***"Theoretical Analysis of Anion Exclusion and Diffusive Transport through Platy-Clay Soils"***. Kluwer Academic Publishers, Transport in Porous Media 57: 251–277, (2004).

19. CHEN Yong-gui, ZHANG Ke-neng , HUANG Chang-bo – ***"Analysis on contaminants transport process through clay-solidified grouting curtain in MSW landfills"***. Journal CSUT Vol. 12, Suppl. 1, pp 168-172, (2005).

20. B. V. S. Viswanadham and H. L. Jessberger – **"Centrifuge Modeling of Geosynthetic Reinforced Clay Liners of Landfills"**. Journal of Geotechnical and Geoenvironmental Engineering, Vol. 131, No. 5, May 1, pp. 564–574, ASCE (2005).

21. İ. Met and H. Akgün - ***"Composite landfill liner design with Ankara clay, Turkey"***. Environ Geol 47: 795–803, Springer-Verlag (2005).

22. Craig B. Lake and R. Kerry Rowe - ***"The 14-year performance of a compacted clay liner used as part of a composite liner system for a leachate***

lagoon”.Geotechnical and Geological Engineering, 23: 657–678, Springer (2005).

23. Fernando O. Marques, Fernando M. S. F. Marques, Anto´ nio Mateus, Jorge Figueiras, Fernando M. Santos, Roge´ rio Mota and Helena Amaral – ***“The effectiveness of ‘‘clay’’ liners as basal isolation of landfills: a case study”.*** Environ Geol 47: 1128–1137, Springer-Verlag (2005).

24. Suman Moro, Khaiwal Ravindra, R. P. Dahiya and A. Chandra (2006) – ***“Leachate Characterization and Assessment of Groundwater Pollution near Municipal Solid* Waste Landfill Site”.** Environmental Monitoring and Assessment, 118**:** 435–456, **S***pringer* (2006).

25. I. K. Tsanis – ***“Modeling Leachate Contamination and Remediation of Groundwater at a Landfill Site”***. Water Resources Management 20: 109–132, Springer (2006).

26. Amer A. Al-Rawas, Yahia E-A. Mohamedzein, Abdulaziz S. AL-Shabibi and Salem AL-Katheiri – ***“Sand–Attapulgite Clay Mixtures as a Landfill Liner”***. Geotechnical and Geological Engineering, 24: 1365–1383, Springer (2006).

27. Kartik Venkatraman, Nanjappa Ashwath **–** ***“Phytocapping: An alternative technique to reduce leachate and methane generation from municipal Landfills”.*** Environmentalist 27:155–164, **S***pringer* (2007).

28. B.V.S. Viswanadham, S. Rajesh, and S.S. Sengupta – ***“Option for Improving the Deformation Behaviour of Compacted Clay Barriers Subjected to Differential Settlements”***. The 12th International Conference of International Association for Computer Methods and Advances in Geomechanics (IACMAG) 1-6 October, pp. 1427-1435, Goa, India (2008)

29. Bharat Jhamnani and S.K. Singh – ***“Evaluation of Organoclays for Use in Landfill Liners”***. The Open Waste Management Journal, 2, 37-42, Bentham Open (2009).

30. Hossam M. Abuel-Naga and Abdelmalek Bouazzab – ***“Numerical Characterization of Advective Gas Flow through GM/GCL Composite Liners Having a Circular Defect in the Geomembrane”***. Journal of Geotechnical and Geoenvironmental Engineering, Vol. 135, No. 11, November 1, pp. 1661-1671, ASCE (2009).

31. Bharat Jhamnani and SK Singh – ***“Groundwater Contamination due to Bhalaswa Landfill Site in New Delhi”,*** International Journal of Environmental Science and Engineering 1:3, pp. 121-125, (2009).

32. Bharat Jhamnani and SK Singh **–** ***“Chloride Transport from Landfills”***, Journal of Institution of Public Health Engineers of India, Vol. 2, pp. 53-57, (2009).

33. R. Kerry Rowe, A. Hoor, and A. Pollard **–** ***“Numerical Examination of a Method for Reducing the Temperature of MSW Landfill Liners”***. Journal of Environmental Engineering, 1-40, ASCE (2010)

34. Sanjay S. Kale, Ajay K. Kadam, Suyash Kumar, N. J. Pawar**–** ***“Evaluating pollution potential of leachate from landfill site, from the Pune metropolitan city and its impact on shallow basaltic aquifers”*** Environ Monit Assess 162:327–346,S*pringer link(2009).*

35. R. Kerry Rowe, M. Z. Islam, R. W. I. Brachman, D. N. Arnepalli and A. Ragab Ewais **–** ***“Antioxidant Depletion from a High Density Polyethylene Geomembrane under Simulated Landfill Conditions”***. Journal of Geotechnical and Geoenvironmental Engineering, July, pp. 930-939, ASCE (2010).

36. Anupam Khajuria, Yugo Yamamoto and Tohru Morioka – ***"Estimation of Municipal Solid Waste Generation and Landfill Area in Asian Developing Countries"***. Journal of Environmental Biology, September, 31(5) 649-654 Lucknow, India (2010).

37. Ritwik Chakraborty and Ambarish Ghosh – ***"Finite Difference Method for Computation of 1-d Pollutant Migration through Saturated Homogeneous Soil Media"***. International Journal of Geomechanics, April 7, pp. 1-27, 2010.

38. George Tchobanoglous, Hilary Theisen and Samuel A. Vigil - ***"Integrated Solid Waste Management: Engineering Principles and Management Issues",*** ISBN**:** 9780071128650, McGraw Hill Publishing Company Limited (1993).

39. Manoj Datta - ***"Waste Disposal in Engineered Landfills",*** ISBN: 81-7319-140-9, Narosa Publishing House (1997).

40. Randall J. Charbeneau – ***"Ground Water Hydraulics and Pollutant Transport",*** ISBN: 0-13-975616-7, Prentice Hall (2000).

41. ***"Manual on Municipal Solid Waste Management"***, Government of India.

42. **Times of India Article.** *http://articles.timesofindia.indiatimes.com/2011-06-28/delhi/29712327_1_landfill-site-solid-waste-slf*

ANNEXURE 1

MATLAB CODE USED TO SOLVE THE PROBLEM

```
clear all % By this all the variables will be cleared

%----------------------------------------------------------------------

%----------------------------------------------------------------------

%========= First define the transprt parameters ======

%----------------------------------------------------------------------

%----------------------------------------------------------------------

ne = 0.54;      %Where ne = effective porosity [no unit]

Tau = 0.050;     %Where Tau = tortuousity [no unit]

Ddiff = 1.08e-9;   %Where Ddiff = molecular diffusion coefficient [m^2/day]

% Now the porous media diffusion coefficient

Dstar = Tau*Ddiff ;%[m^2/day]%Where Dstar = effective diffusion coefficient

%----------------------------------------------------------------------

%----------------------------------------------------------------------

%=========== Now plot analytical solution ==========

%----------------------------------------------------------------------

%----------------------------------------------------------------------

%First generate vector of x values to use for plotting

%how far out in x should we go?
```

```
%let’s use characteristic length scale for diffusion for 50 years)

xmax = 3*(2*sqrt(Dstar*50));

%column vector with 200 values linearly spaced from x=0 to x=xmax

x=linspace(0,xmax,200);

% (’) is the transpose operator that

% converts row vector to column vector

% The (;) suppresses screen output of the array

% Now, let’s define an array of the time values

t = [0.5, 10, 50]; %[t= Time in years]

%now intialize the array in which the analytic

%concentration values will be stored

CAS = zeros(length(x),length(t));

%creates array of all zeros

% CAS = [0 0 0 ]

% [0 0 0 ]

% [. . . ]

% [. . . ]

% [. . . ]

% [0 0 0 ]

% now calc the ANALYTIC SOLUTION

% Now the cycle through and calc the concs for
```

```
% all the x-values for each time

for i=1:length(t); %cycle through each time value

B = (x)./(2.*sqrt(Dstar.*t(i)));

CAS(:,i)=erfc(B); %evaluate

end

%so this calcs an entire column all at once


%------------------------------------------------------------------------------

%------------------------------------------------------------------------------

%=============== Now plot the solution =============

%------------------------------------------------------------------------------

%------------------------------------------------------------------------------

figure(1),clf

%this opens figure(1)

%(and "clf" clears it in case we had something on it before)

plot(x,CAS(:,1),'k-');

%plot profile for first time value with black (k)

% solid line (-)

%type "help plot" at command prompt ">>" for more options

hold on;

%"hold on" keeps the plot window open so more things will
```

```
%be added to it

%(other wise, MATLAB will clear the graph before plotting again)

plot(x,CAS(:,2),'r--')

%plot profile for second time value with red (r)

% dashed line (--)

plot(x,CAS(:,3),'b-.')

%plot profile for thirdtime value with blue (b)

% dash-dotted line (-.)

%Now let’s add the axis labels

xlabel('x [m]','fontsize',14)

ylabel('C(x,t)/C_0','fontsize',14)

%title

title('The Solution of ADE with v_x=0','fontsize',14)

%And now our legend:

legend('t=0.5 Years','t=10 Years','t=50 Years')


%======= The End ===============
```

ANNEXURE 2

DATA SHEETS

2.1 FOR COMPACTED CLAY LANDFILL LINER MATERIAL

ne= 0.37
τ= 0.10
D_d= 6.91E-06
D_s= 6.91E-07
x_{max}= 3.53E-02

S.N.	x	C			C/C_0 (Concentration Ratio)		
		t=0.5	t=10	t=50	t=0.5	t=10	t=50
1	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1	1	1
2	1.76E-04	1.50E-01	3.35E-02	1.50E-02	0.832004	0.962167	0.983076
3	3.53E-04	3.00E-01	6.71E-02	3.00E-02	0.671373	0.924419	0.966159
4	5.29E-04	4.50E-01	1.01E-01	4.50E-02	0.524518	0.886841	0.949257
5	7.05E-04	6.00E-01	1.34E-01	6.00E-02	0.396144	0.849515	0.932378
6	8.82E-04	7.50E-01	1.68E-01	7.50E-02	0.288845	0.812524	0.91553
7	1.06E-03	9.00E-01	2.01E-01	9.00E-02	0.203092	0.775947	0.898719
8	1.23E-03	1.05E+00	2.35E-01	1.05E-01	0.137564	0.73986	0.881954
9	1.41E-03	1.20E+00	2.68E-01	1.20E-01	0.089686	0.704336	0.865242
10	1.59E-03	1.35E+00	3.02E-01	1.35E-01	0.056238	0.669447	0.848589
11	1.76E-03	1.50E+00	3.35E-01	1.50E-01	0.033895	0.635256	0.832004
12	1.94E-03	1.65E+00	3.69E-01	1.65E-01	0.019624	0.601826	0.815493
13	2.12E-03	1.80E+00	4.02E-01	1.80E-01	0.010909	0.569214	0.799064
14	2.29E-03	1.95E+00	4.36E-01	1.95E-01	0.005821	0.537469	0.782723
15	2.47E-03	2.10E+00	4.70E-01	2.10E-01	0.002979	0.50664	0.766478
16	2.65E-03	2.25E+00	5.03E-01	2.25E-01	0.001463	0.476767	0.750335
17	2.82E-03	2.40E+00	5.37E-01	2.40E-01	0.000689	0.447884	0.7343
18	3.00E-03	2.55E+00	5.70E-01	2.55E-01	0.000311	0.420023	0.71838
19	3.17E-03	2.70E+00	6.04E-01	2.70E-01	0.000134	0.393208	0.702582
20	3.35E-03	2.85E+00	6.37E-01	2.85E-01	5.57E-05	0.367456	0.686911
21	3.53E-03	3.00E+00	6.71E-01	3.00E-01	2.21E-05	0.342782	0.671373
22	3.70E-03	3.15E+00	7.04E-01	3.15E-01	8.4E-06	0.319193	0.655975
23	3.88E-03	3.30E+00	7.38E-01	3.30E-01	3.06E-06	0.296693	0.640721
24	4.06E-03	3.45E+00	7.71E-01	3.45E-01	1.07E-06	0.275279	0.625618
25	4.23E-03	3.60E+00	8.05E-01	3.60E-01	3.56E-07	0.254945	0.61067
26	4.41E-03	3.75E+00	8.39E-01	3.75E-01	1.14E-07	0.23568	0.595883
27	4.58E-03	3.90E+00	8.72E-01	3.90E-01	3.48E-08	0.217468	0.581261

28	4.76E-03	4.05E+00	9.06E-01	4.05E-01	1.02E-08	0.200291	0.56681
29	4.94E-03	4.20E+00	9.39E-01	4.20E-01	2.86E-09	0.184126	0.552532
30	5.11E-03	4.35E+00	9.73E-01	4.35E-01	7.66E-10	0.168948	0.538434
31	5.29E-03	4.50E+00	1.01E+00	4.50E-01	1.97E-10	0.154729	0.524518
32	5.47E-03	4.65E+00	1.04E+00	4.65E-01	4.83E-11	0.141437	0.510789
33	5.64E-03	4.80E+00	1.07E+00	4.80E-01	1.14E-11	0.129041	0.49725
34	5.82E-03	4.95E+00	1.11E+00	4.95E-01	2.55E-12	0.117506	0.483905
35	6.00E-03	5.10E+00	1.14E+00	5.10E-01	5.49E-13	0.106796	0.470756
36	6.17E-03	5.25E+00	1.17E+00	5.25E-01	1.13E-13	0.096875	0.457807
37	6.35E-03	5.40E+00	1.21E+00	5.40E-01	2.23E-14	0.087705	0.445061
38	6.52E-03	5.55E+00	1.24E+00	5.55E-01	4.22E-15	0.079248	0.432519
39	6.70E-03	5.70E+00	1.27E+00	5.70E-01	7.77E-16	0.071467	0.420184
40	6.88E-03	5.85E+00	1.31E+00	5.85E-01	1.11E-16	0.064323	0.408059
41	7.05E-03	6.00E+00	1.34E+00	6.00E-01	0	0.05778	0.396144
42	7.23E-03	6.15E+00	1.38E+00	6.15E-01	0	0.051799	0.384442
43	7.41E-03	6.30E+00	1.41E+00	6.30E-01	0	0.046345	0.372954
44	7.58E-03	6.45E+00	1.44E+00	6.45E-01	0	0.041383	0.36168
45	7.76E-03	6.60E+00	1.48E+00	6.60E-01	0	0.036879	0.350623
46	7.94E-03	6.75E+00	1.51E+00	6.75E-01	0	0.032799	0.339783
47	8.11E-03	6.90E+00	1.54E+00	6.90E-01	0	0.029112	0.32916
48	8.29E-03	7.05E+00	1.58E+00	7.05E-01	0	0.025787	0.318755
49	8.46E-03	7.20E+00	1.61E+00	7.20E-01	0	0.022796	0.308567
50	8.64E-03	7.35E+00	1.64E+00	7.35E-01	0	0.020111	0.298597
51	8.82E-03	7.50E+00	1.68E+00	7.50E-01	0	0.017706	0.288845
52	8.99E-03	7.65E+00	1.71E+00	7.65E-01	0	0.015557	0.279309
53	9.17E-03	7.80E+00	1.74E+00	7.80E-01	0	0.013641	0.26999
54	9.35E-03	7.95E+00	1.78E+00	7.95E-01	0	0.011937	0.260886
55	9.52E-03	8.10E+00	1.81E+00	8.10E-01	0	0.010424	0.251997
56	9.70E-03	8.25E+00	1.84E+00	8.25E-01	0	0.009084	0.243321
57	9.87E-03	8.40E+00	1.88E+00	8.40E-01	0	0.0079	0.234857
58	1.01E-02	8.55E+00	1.91E+00	8.55E-01	0	0.006856	0.226604
59	1.02E-02	8.70E+00	1.95E+00	8.70E-01	0	0.005938	0.21856
60	1.04E-02	8.85E+00	1.98E+00	8.85E-01	0	0.005132	0.210723
61	1.06E-02	9.00E+00	2.01E+00	9.00E-01	0	0.004427	0.203092
62	1.08E-02	9.15E+00	2.05E+00	9.15E-01	0	0.00381	0.195664
63	1.09E-02	9.30E+00	2.08E+00	9.30E-01	0	0.003272	0.188437
64	1.11E-02	9.45E+00	2.11E+00	9.45E-01	0	0.002805	0.181408
65	1.13E-02	9.60E+00	2.15E+00	9.60E-01	0	0.002399	0.174576
66	1.15E-02	9.75E+00	2.18E+00	9.75E-01	0	0.002048	0.167939
67	1.16E-02	9.90E+00	2.21E+00	9.90E-01	0	0.001744	0.161492
68	1.18E-02	1.01E+01	2.25E+00	1.01E+00	0	0.001482	0.155234

69	1.20E-02	1.02E+01	2.28E+00	1.02E+00	0	0.001257	0.149162
70	1.22E-02	1.04E+01	2.31E+00	1.04E+00	0	0.001064	0.143273
71	1.23E-02	1.05E+01	2.35E+00	1.05E+00	0	0.000899	0.137564
72	1.25E-02	1.07E+01	2.38E+00	1.07E+00	0	0.000758	0.132032
73	1.27E-02	1.08E+01	2.41E+00	1.08E+00	0	0.000637	0.126674
74	1.29E-02	1.10E+01	2.45E+00	1.10E+00	0	0.000535	0.121487
75	1.30E-02	1.11E+01	2.48E+00	1.11E+00	0	0.000448	0.116467
76	1.32E-02	1.13E+01	2.52E+00	1.13E+00	0	0.000374	0.111612
77	1.34E-02	1.14E+01	2.55E+00	1.14E+00	0	0.000312	0.106918
78	1.36E-02	1.16E+01	2.58E+00	1.16E+00	0	0.00026	0.102381
79	1.38E-02	1.17E+01	2.62E+00	1.17E+00	0	0.000216	0.098
80	1.39E-02	1.19E+01	2.65E+00	1.19E+00	0	0.000179	0.093769
81	1.41E-02	1.20E+01	2.68E+00	1.20E+00	0	0.000148	0.089686
82	1.43E-02	1.22E+01	2.72E+00	1.22E+00	0	0.000122	0.085747
83	1.45E-02	1.23E+01	2.75E+00	1.23E+00	0	0.0001	0.08195
84	1.46E-02	1.25E+01	2.78E+00	1.25E+00	0	8.25E-05	0.07829
85	1.48E-02	1.26E+01	2.82E+00	1.26E+00	0	6.76E-05	0.074764
86	1.50E-02	1.28E+01	2.85E+00	1.28E+00	0	5.53E-05	0.071369
87	1.52E-02	1.29E+01	2.88E+00	1.29E+00	0	4.52E-05	0.068101
88	1.53E-02	1.31E+01	2.92E+00	1.31E+00	0	3.68E-05	0.064958
89	1.55E-02	1.32E+01	2.95E+00	1.32E+00	0	2.99E-05	0.061935
90	1.57E-02	1.34E+01	2.99E+00	1.34E+00	0	2.43E-05	0.059029
91	1.59E-02	1.35E+01	3.02E+00	1.35E+00	0	1.96E-05	0.056238
92	1.60E-02	1.37E+01	3.05E+00	1.37E+00	0	1.59E-05	0.053557
93	1.62E-02	1.38E+01	3.09E+00	1.38E+00	0	1.28E-05	0.050984
94	1.64E-02	1.40E+01	3.12E+00	1.40E+00	0	1.03E-05	0.048515
95	1.66E-02	1.41E+01	3.15E+00	1.41E+00	0	8.24E-06	0.046148
96	1.68E-02	1.43E+01	3.19E+00	1.43E+00	0	6.6E-06	0.043878
97	1.69E-02	1.44E+01	3.22E+00	1.44E+00	0	5.27E-06	0.041703
98	1.71E-02	1.46E+01	3.25E+00	1.46E+00	0	4.2E-06	0.039621
99	1.73E-02	1.47E+01	3.29E+00	1.47E+00	0	3.34E-06	0.037627
100	1.75E-02	1.49E+01	3.32E+00	1.49E+00	0	2.65E-06	0.035719
101	1.76E-02	1.50E+01	3.35E+00	1.50E+00	0	2.1E-06	0.033895
102	1.78E-02	1.52E+01	3.39E+00	1.52E+00	0	1.66E-06	0.032151
103	1.80E-02	1.53E+01	3.42E+00	1.53E+00	0	1.31E-06	0.030484
104	1.82E-02	1.55E+01	3.45E+00	1.55E+00	0	1.03E-06	0.028892
105	1.83E-02	1.56E+01	3.49E+00	1.56E+00	0	8.09E-07	0.027372
106	1.85E-02	1.58E+01	3.52E+00	1.58E+00	0	6.34E-07	0.025921
107	1.87E-02	1.59E+01	3.56E+00	1.59E+00	0	4.96E-07	0.024538
108	1.89E-02	1.61E+01	3.59E+00	1.61E+00	0	3.87E-07	0.023219
109	1.90E-02	1.62E+01	3.62E+00	1.62E+00	0	3.01E-07	0.021962

110	1.92E-02	1.64E+01	3.66E+00	1.64E+00	0	2.34E-07	0.020765
111	1.94E-02	1.65E+01	3.69E+00	1.65E+00	0	1.81E-07	0.019624
112	1.96E-02	1.67E+01	3.72E+00	1.67E+00	0	1.4E-07	0.018539
113	1.97E-02	1.68E+01	3.76E+00	1.68E+00	0	1.08E-07	0.017507
114	1.99E-02	1.70E+01	3.79E+00	1.70E+00	0	8.32E-08	0.016526
115	2.01E-02	1.71E+01	3.82E+00	1.71E+00	0	6.39E-08	0.015593
116	2.03E-02	1.73E+01	3.86E+00	1.73E+00	0	4.9E-08	0.014707
117	2.05E-02	1.74E+01	3.89E+00	1.74E+00	0	3.75E-08	0.013865
118	2.06E-02	1.76E+01	3.92E+00	1.76E+00	0	2.86E-08	0.013067
119	2.08E-02	1.77E+01	3.96E+00	1.77E+00	0	2.18E-08	0.012309
120	2.10E-02	1.79E+01	3.99E+00	1.79E+00	0	1.66E-08	0.011591
121	2.12E-02	1.80E+01	4.02E+00	1.80E+00	0	1.25E-08	0.010909
122	2.13E-02	1.82E+01	4.06E+00	1.82E+00	0	9.49E-09	0.010264
123	2.15E-02	1.83E+01	4.09E+00	1.83E+00	0	7.17E-09	0.009653
124	2.17E-02	1.85E+01	4.13E+00	1.85E+00	0	5.4E-09	0.009075
125	2.19E-02	1.86E+01	4.16E+00	1.86E+00	0	4.06E-09	0.008528
126	2.20E-02	1.88E+01	4.19E+00	1.88E+00	0	3.04E-09	0.00801
127	2.22E-02	1.89E+01	4.23E+00	1.89E+00	0	2.28E-09	0.007521
128	2.24E-02	1.91E+01	4.26E+00	1.91E+00	0	1.7E-09	0.007058
129	2.26E-02	1.92E+01	4.29E+00	1.92E+00	0	1.27E-09	0.006622
130	2.27E-02	1.94E+01	4.33E+00	1.94E+00	0	9.42E-10	0.00621
131	2.29E-02	1.95E+01	4.36E+00	1.95E+00	0	6.98E-10	0.005821
132	2.31E-02	1.97E+01	4.39E+00	1.97E+00	0	5.17E-10	0.005454
133	2.33E-02	1.98E+01	4.43E+00	1.98E+00	0	3.82E-10	0.005108
134	2.35E-02	2.00E+01	4.46E+00	2.00E+00	0	2.81E-10	0.004782
135	2.36E-02	2.01E+01	4.49E+00	2.01E+00	0	2.07E-10	0.004475
136	2.38E-02	2.03E+01	4.53E+00	2.03E+00	0	1.52E-10	0.004186
137	2.40E-02	2.04E+01	4.56E+00	2.04E+00	0	1.11E-10	0.003914
138	2.42E-02	2.06E+01	4.60E+00	2.06E+00	0	8.11E-11	0.003658
139	2.43E-02	2.07E+01	4.63E+00	2.07E+00	0	5.91E-11	0.003418
140	2.45E-02	2.09E+01	4.66E+00	2.09E+00	0	4.3E-11	0.003192
141	2.47E-02	2.10E+01	4.70E+00	2.10E+00	0	3.12E-11	0.002979
142	2.49E-02	2.12E+01	4.73E+00	2.12E+00	0	2.26E-11	0.00278
143	2.50E-02	2.13E+01	4.76E+00	2.13E+00	0	1.63E-11	0.002593
144	2.52E-02	2.15E+01	4.80E+00	2.15E+00	0	1.18E-11	0.002417
145	2.54E-02	2.16E+01	4.83E+00	2.16E+00	0	8.46E-12	0.002253
146	2.56E-02	2.18E+01	4.86E+00	2.18E+00	0	6.07E-12	0.002099
147	2.57E-02	2.19E+01	4.90E+00	2.19E+00	0	4.35E-12	0.001954
148	2.59E-02	2.21E+01	4.93E+00	2.21E+00	0	3.11E-12	0.001819
149	2.61E-02	2.22E+01	4.96E+00	2.22E+00	0	2.21E-12	0.001692
150	2.63E-02	2.24E+01	5.00E+00	2.24E+00	0	1.58E-12	0.001574

151	2.65E-02	2.25E+01	5.03E+00	2.25E+00	0	1.12E-12	0.001463
152	2.66E-02	2.27E+01	5.06E+00	2.27E+00	0	7.92E-13	0.001359
153	2.68E-02	2.28E+01	5.10E+00	2.28E+00	0	5.6E-13	0.001262
154	2.70E-02	2.30E+01	5.13E+00	2.30E+00	0	3.95E-13	0.001172
155	2.72E-02	2.31E+01	5.17E+00	2.31E+00	0	2.78E-13	0.001088
156	2.73E-02	2.33E+01	5.20E+00	2.33E+00	0	1.95E-13	0.001009
157	2.75E-02	2.34E+01	5.23E+00	2.34E+00	0	1.36E-13	0.000935
158	2.77E-02	2.36E+01	5.27E+00	2.36E+00	0	9.54E-14	0.000867
159	2.79E-02	2.37E+01	5.30E+00	2.37E+00	0	6.65E-14	0.000803
160	2.80E-02	2.39E+01	5.33E+00	2.39E+00	0	4.63E-14	0.000744
161	2.82E-02	2.40E+01	5.37E+00	2.40E+00	0	3.21E-14	0.000689
162	2.84E-02	2.42E+01	5.40E+00	2.42E+00	0	2.22E-14	0.000637
163	2.86E-02	2.43E+01	5.43E+00	2.43E+00	0	1.54E-14	0.000589
164	2.87E-02	2.45E+01	5.47E+00	2.45E+00	0	1.07E-14	0.000545
165	2.89E-02	2.46E+01	5.50E+00	2.46E+00	0	7.33E-15	0.000503
166	2.91E-02	2.48E+01	5.53E+00	2.48E+00	0	5E-15	0.000465
167	2.93E-02	2.49E+01	5.57E+00	2.49E+00	0	3.44E-15	0.000429
168	2.94E-02	2.51E+01	5.60E+00	2.51E+00	0	2.33E-15	0.000396
169	2.96E-02	2.52E+01	5.63E+00	2.52E+00	0	1.55E-15	0.000365
170	2.98E-02	2.54E+01	5.67E+00	2.54E+00	0	1.11E-15	0.000337
171	3.00E-02	2.55E+01	5.70E+00	2.55E+00	0	7.77E-16	0.000311
172	3.02E-02	2.57E+01	5.74E+00	2.57E+00	0	5.55E-16	0.000286
173	3.03E-02	2.58E+01	5.77E+00	2.58E+00	0	3.33E-16	0.000264
174	3.05E-02	2.60E+01	5.80E+00	2.60E+00	0	2.22E-16	0.000243
175	3.07E-02	2.61E+01	5.84E+00	2.61E+00	0	1.11E-16	0.000223
176	3.09E-02	2.63E+01	5.87E+00	2.63E+00	0	1.11E-16	0.000205
177	3.10E-02	2.64E+01	5.90E+00	2.64E+00	0	1.11E-16	0.000189
178	3.12E-02	2.66E+01	5.94E+00	2.66E+00	0	0	0.000174
179	3.14E-02	2.67E+01	5.97E+00	2.67E+00	0	0	0.000159
180	3.16E-02	2.69E+01	6.00E+00	2.69E+00	0	0	0.000146
181	3.17E-02	2.70E+01	6.04E+00	2.70E+00	0	0	0.000134
182	3.19E-02	2.72E+01	6.07E+00	2.72E+00	0	0	0.000123
183	3.21E-02	2.73E+01	6.10E+00	2.73E+00	0	0	0.000113
184	3.23E-02	2.75E+01	6.14E+00	2.75E+00	0	0	0.000104
185	3.24E-02	2.76E+01	6.17E+00	2.76E+00	0	0	9.49E-05
186	3.26E-02	2.78E+01	6.21E+00	2.78E+00	0	0	8.69E-05
187	3.28E-02	2.79E+01	6.24E+00	2.79E+00	0	0	7.96E-05
188	3.30E-02	2.81E+01	6.27E+00	2.81E+00	0	0	7.28E-05
189	3.32E-02	2.82E+01	6.31E+00	2.82E+00	0	0	6.66E-05
190	3.33E-02	2.84E+01	6.34E+00	2.84E+00	0	0	6.09E-05
191	3.35E-02	2.85E+01	6.37E+00	2.85E+00	0	0	5.57E-05

192	3.37E-02	2.87E+01	6.41E+00	2.87E+00	0	0	5.08E-05
193	3.39E-02	2.88E+01	6.44E+00	2.88E+00	0	0	4.64E-05
194	3.40E-02	2.90E+01	6.47E+00	2.90E+00	0	0	4.24E-05
195	3.42E-02	2.91E+01	6.51E+00	2.91E+00	0	0	3.87E-05
196	3.44E-02	2.93E+01	6.54E+00	2.93E+00	0	0	3.53E-05
197	3.46E-02	2.94E+01	6.57E+00	2.94E+00	0	0	3.21E-05
198	3.47E-02	2.96E+01	6.61E+00	2.96E+00	0	0	2.93E-05
199	3.49E-02	2.97E+01	6.64E+00	2.97E+00	0	0	2.67E-05
200	3.51E-02	2.99E+01	6.67E+00	2.99E+00	0	0	2.43E-05

2.2 FOR GEOSYNTHETICS LANDFILL LINER MATERIAL

ne= 0.66
τ= 0.34
D_d= 1.98E-05
D_s= 6.73E-06
x_{max}= 1.10E-01

S.N.	x	C			C/C_0 (Concentration Ratio)		
		t=0.5	t=10	t=50	t=0.5	t=10	t=50
1	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1	1	1
2	5.50E-04	1.50E-01	3.35E-02	1.50E-02	0.832004	0.962167	0.983076
3	1.10E-03	3.00E-01	6.71E-02	3.00E-02	0.671373	0.924419	0.966159
4	1.65E-03	4.50E-01	1.01E-01	4.50E-02	0.524518	0.886841	0.949257
5	2.20E-03	6.00E-01	1.34E-01	6.00E-02	0.396144	0.849515	0.932378
6	2.75E-03	7.50E-01	1.68E-01	7.50E-02	0.288845	0.812524	0.91553
7	3.30E-03	9.00E-01	2.01E-01	9.00E-02	0.203092	0.775947	0.898719
8	3.85E-03	1.05E+00	2.35E-01	1.05E-01	0.137564	0.73986	0.881954
9	4.40E-03	1.20E+00	2.68E-01	1.20E-01	0.089686	0.704336	0.865242
10	4.95E-03	1.35E+00	3.02E-01	1.35E-01	0.056238	0.669447	0.848589
11	5.50E-03	1.50E+00	3.35E-01	1.50E-01	0.033895	0.635256	0.832004
12	6.05E-03	1.65E+00	3.69E-01	1.65E-01	0.019624	0.601826	0.815493
13	6.60E-03	1.80E+00	4.02E-01	1.80E-01	0.010909	0.569214	0.799064
14	7.16E-03	1.95E+00	4.36E-01	1.95E-01	0.005821	0.537469	0.782723
15	7.71E-03	2.10E+00	4.70E-01	2.10E-01	0.002979	0.50664	0.766478
16	8.26E-03	2.25E+00	5.03E-01	2.25E-01	0.001463	0.476767	0.750335
17	8.81E-03	2.40E+00	5.37E-01	2.40E-01	0.000689	0.447884	0.7343
18	9.36E-03	2.55E+00	5.70E-01	2.55E-01	0.000311	0.420023	0.71838
19	9.91E-03	2.70E+00	6.04E-01	2.70E-01	0.000134	0.393208	0.702582
20	1.05E-02	2.85E+00	6.37E-01	2.85E-01	5.57E-05	0.367456	0.686911
21	1.10E-02	3.00E+00	6.71E-01	3.00E-01	2.21E-05	0.342782	0.671373
22	1.16E-02	3.15E+00	7.04E-01	3.15E-01	8.4E-06	0.319193	0.655975
23	1.21E-02	3.30E+00	7.38E-01	3.30E-01	3.06E-06	0.296693	0.640721
24	1.27E-02	3.45E+00	7.71E-01	3.45E-01	1.07E-06	0.275279	0.625618
25	1.32E-02	3.60E+00	8.05E-01	3.60E-01	3.56E-07	0.254945	0.61067
26	1.38E-02	3.75E+00	8.39E-01	3.75E-01	1.14E-07	0.23568	0.595883
27	1.43E-02	3.90E+00	8.72E-01	3.90E-01	3.48E-08	0.217468	0.581261
28	1.49E-02	4.05E+00	9.06E-01	4.05E-01	1.02E-08	0.200291	0.56681
29	1.54E-02	4.20E+00	9.39E-01	4.20E-01	2.86E-09	0.184126	0.552532
30	1.60E-02	4.35E+00	9.73E-01	4.35E-01	7.66E-10	0.168948	0.538434
31	1.65E-02	4.50E+00	1.01E+00	4.50E-01	1.97E-10	0.154729	0.524518
32	1.71E-02	4.65E+00	1.04E+00	4.65E-01	4.83E-11	0.141437	0.510789

33	1.76E-02	4.80E+00	1.07E+00	4.80E-01	1.14E-11	0.129041	0.49725
34	1.82E-02	4.95E+00	1.11E+00	4.95E-01	2.55E-12	0.117506	0.483905
35	1.87E-02	5.10E+00	1.14E+00	5.10E-01	5.49E-13	0.106796	0.470756
36	1.93E-02	5.25E+00	1.17E+00	5.25E-01	1.13E-13	0.096875	0.457807
37	1.98E-02	5.40E+00	1.21E+00	5.40E-01	2.23E-14	0.087705	0.445061
38	2.04E-02	5.55E+00	1.24E+00	5.55E-01	4.22E-15	0.079248	0.432519
39	2.09E-02	5.70E+00	1.27E+00	5.70E-01	7.77E-16	0.071467	0.420184
40	2.15E-02	5.85E+00	1.31E+00	5.85E-01	1.11E-16	0.064323	0.408059
41	2.20E-02	6.00E+00	1.34E+00	6.00E-01	0	0.05778	0.396144
42	2.26E-02	6.15E+00	1.38E+00	6.15E-01	0	0.051799	0.384442
43	2.31E-02	6.30E+00	1.41E+00	6.30E-01	0	0.046345	0.372954
44	2.37E-02	6.45E+00	1.44E+00	6.45E-01	0	0.041383	0.36168
45	2.42E-02	6.60E+00	1.48E+00	6.60E-01	0	0.036879	0.350623
46	2.48E-02	6.75E+00	1.51E+00	6.75E-01	0	0.032799	0.339783
47	2.53E-02	6.90E+00	1.54E+00	6.90E-01	0	0.029112	0.32916
48	2.59E-02	7.05E+00	1.58E+00	7.05E-01	0	0.025787	0.318755
49	2.64E-02	7.20E+00	1.61E+00	7.20E-01	0	0.022796	0.308567
50	2.70E-02	7.35E+00	1.64E+00	7.35E-01	0	0.020111	0.298597
51	2.75E-02	7.50E+00	1.68E+00	7.50E-01	0	0.017706	0.288845
52	2.81E-02	7.65E+00	1.71E+00	7.65E-01	0	0.015557	0.279309
53	2.86E-02	7.80E+00	1.74E+00	7.80E-01	0	0.013641	0.26999
54	2.92E-02	7.95E+00	1.78E+00	7.95E-01	0	0.011937	0.260886
55	2.97E-02	8.10E+00	1.81E+00	8.10E-01	0	0.010424	0.251997
56	3.03E-02	8.25E+00	1.84E+00	8.25E-01	0	0.009084	0.243321
57	3.08E-02	8.40E+00	1.88E+00	8.40E-01	0	0.0079	0.234857
58	3.14E-02	8.55E+00	1.91E+00	8.55E-01	0	0.006856	0.226604
59	3.19E-02	8.70E+00	1.95E+00	8.70E-01	0	0.005938	0.21856
60	3.25E-02	8.85E+00	1.98E+00	8.85E-01	0	0.005132	0.210723
61	3.30E-02	9.00E+00	2.01E+00	9.00E-01	0	0.004427	0.203092
62	3.36E-02	9.15E+00	2.05E+00	9.15E-01	0	0.00381	0.195664
63	3.41E-02	9.30E+00	2.08E+00	9.30E-01	0	0.003272	0.188437
64	3.47E-02	9.45E+00	2.11E+00	9.45E-01	0	0.002805	0.181408
65	3.52E-02	9.60E+00	2.15E+00	9.60E-01	0	0.002399	0.174576
66	3.58E-02	9.75E+00	2.18E+00	9.75E-01	0	0.002048	0.167939
67	3.63E-02	9.90E+00	2.21E+00	9.90E-01	0	0.001744	0.161492
68	3.69E-02	1.01E+01	2.25E+00	1.01E+00	0	0.001482	0.155234
69	3.74E-02	1.02E+01	2.28E+00	1.02E+00	0	0.001257	0.149162
70	3.80E-02	1.04E+01	2.31E+00	1.04E+00	0	0.001064	0.143273
71	3.85E-02	1.05E+01	2.35E+00	1.05E+00	0	0.000899	0.137564
72	3.91E-02	1.07E+01	2.38E+00	1.07E+00	0	0.000758	0.132032
73	3.96E-02	1.08E+01	2.41E+00	1.08E+00	0	0.000637	0.126674

74	4.02E-02	1.10E+01	2.45E+00	1.10E+00	0	0.000535	0.121487
75	4.07E-02	1.11E+01	2.48E+00	1.11E+00	0	0.000448	0.116467
76	4.13E-02	1.13E+01	2.52E+00	1.13E+00	0	0.000374	0.111612
77	4.18E-02	1.14E+01	2.55E+00	1.14E+00	0	0.000312	0.106918
78	4.24E-02	1.16E+01	2.58E+00	1.16E+00	0	0.00026	0.102381
79	4.29E-02	1.17E+01	2.62E+00	1.17E+00	0	0.000216	0.098
80	4.35E-02	1.19E+01	2.65E+00	1.19E+00	0	0.000179	0.093769
81	4.40E-02	1.20E+01	2.68E+00	1.20E+00	0	0.000148	0.089686
82	4.46E-02	1.22E+01	2.72E+00	1.22E+00	0	0.000122	0.085747
83	4.51E-02	1.23E+01	2.75E+00	1.23E+00	0	0.0001	0.08195
84	4.57E-02	1.25E+01	2.78E+00	1.25E+00	0	8.25E-05	0.07829
85	4.62E-02	1.26E+01	2.82E+00	1.26E+00	0	6.76E-05	0.074764
86	4.68E-02	1.28E+01	2.85E+00	1.28E+00	0	5.53E-05	0.071369
87	4.73E-02	1.29E+01	2.88E+00	1.29E+00	0	4.52E-05	0.068101
88	4.79E-02	1.31E+01	2.92E+00	1.31E+00	0	3.68E-05	0.064958
89	4.84E-02	1.32E+01	2.95E+00	1.32E+00	0	2.99E-05	0.061935
90	4.90E-02	1.34E+01	2.99E+00	1.34E+00	0	2.43E-05	0.059029
91	4.95E-02	1.35E+01	3.02E+00	1.35E+00	0	1.96E-05	0.056238
92	5.01E-02	1.37E+01	3.05E+00	1.37E+00	0	1.59E-05	0.053557
93	5.06E-02	1.38E+01	3.09E+00	1.38E+00	0	1.28E-05	0.050984
94	5.12E-02	1.40E+01	3.12E+00	1.40E+00	0	1.03E-05	0.048515
95	5.17E-02	1.41E+01	3.15E+00	1.41E+00	0	8.24E-06	0.046148
96	5.23E-02	1.43E+01	3.19E+00	1.43E+00	0	6.6E-06	0.043878
97	5.28E-02	1.44E+01	3.22E+00	1.44E+00	0	5.27E-06	0.041703
98	5.34E-02	1.46E+01	3.25E+00	1.46E+00	0	4.2E-06	0.039621
99	5.39E-02	1.47E+01	3.29E+00	1.47E+00	0	3.34E-06	0.037627
100	5.45E-02	1.49E+01	3.32E+00	1.49E+00	0	2.65E-06	0.035719
101	5.50E-02	1.50E+01	3.35E+00	1.50E+00	0	2.1E-06	0.033895
102	5.56E-02	1.52E+01	3.39E+00	1.52E+00	0	1.66E-06	0.032151
103	5.61E-02	1.53E+01	3.42E+00	1.53E+00	0	1.31E-06	0.030484
104	5.67E-02	1.55E+01	3.45E+00	1.55E+00	0	1.03E-06	0.028892
105	5.72E-02	1.56E+01	3.49E+00	1.56E+00	0	8.09E-07	0.027372
106	5.78E-02	1.58E+01	3.52E+00	1.58E+00	0	6.34E-07	0.025921
107	5.83E-02	1.59E+01	3.56E+00	1.59E+00	0	4.96E-07	0.024538
108	5.89E-02	1.61E+01	3.59E+00	1.61E+00	0	3.87E-07	0.023219
109	5.94E-02	1.62E+01	3.62E+00	1.62E+00	0	3.01E-07	0.021962
110	6.00E-02	1.64E+01	3.66E+00	1.64E+00	0	2.34E-07	0.020765
111	6.05E-02	1.65E+01	3.69E+00	1.65E+00	0	1.81E-07	0.019624
112	6.11E-02	1.67E+01	3.72E+00	1.67E+00	0	1.4E-07	0.018539
113	6.16E-02	1.68E+01	3.76E+00	1.68E+00	0	1.08E-07	0.017507
114	6.22E-02	1.70E+01	3.79E+00	1.70E+00	0	8.32E-08	0.016526

115	6.27E-02	1.71E+01	3.82E+00	1.71E+00	0	6.39E-08	0.015593
116	6.33E-02	1.73E+01	3.86E+00	1.73E+00	0	4.9E-08	0.014707
117	6.38E-02	1.74E+01	3.89E+00	1.74E+00	0	3.75E-08	0.013865
118	6.44E-02	1.76E+01	3.92E+00	1.76E+00	0	2.86E-08	0.013067
119	6.49E-02	1.77E+01	3.96E+00	1.77E+00	0	2.18E-08	0.012309
120	6.55E-02	1.79E+01	3.99E+00	1.79E+00	0	1.66E-08	0.011591
121	6.60E-02	1.80E+01	4.02E+00	1.80E+00	0	1.25E-08	0.010909
122	6.66E-02	1.82E+01	4.06E+00	1.82E+00	0	9.49E-09	0.010264
123	6.71E-02	1.83E+01	4.09E+00	1.83E+00	0	7.17E-09	0.009653
124	6.77E-02	1.85E+01	4.13E+00	1.85E+00	0	5.4E-09	0.009075
125	6.82E-02	1.86E+01	4.16E+00	1.86E+00	0	4.06E-09	0.008528
126	6.88E-02	1.88E+01	4.19E+00	1.88E+00	0	3.04E-09	0.00801
127	6.94E-02	1.89E+01	4.23E+00	1.89E+00	0	2.28E-09	0.007521
128	6.99E-02	1.91E+01	4.26E+00	1.91E+00	0	1.7E-09	0.007058
129	7.05E-02	1.92E+01	4.29E+00	1.92E+00	0	1.27E-09	0.006622
130	7.10E-02	1.94E+01	4.33E+00	1.94E+00	0	9.42E-10	0.00621
131	7.16E-02	1.95E+01	4.36E+00	1.95E+00	0	6.98E-10	0.005821
132	7.21E-02	1.97E+01	4.39E+00	1.97E+00	0	5.17E-10	0.005454
133	7.27E-02	1.98E+01	4.43E+00	1.98E+00	0	3.82E-10	0.005108
134	7.32E-02	2.00E+01	4.46E+00	2.00E+00	0	2.81E-10	0.004782
135	7.38E-02	2.01E+01	4.49E+00	2.01E+00	0	2.07E-10	0.004475
136	7.43E-02	2.03E+01	4.53E+00	2.03E+00	0	1.52E-10	0.004186
137	7.49E-02	2.04E+01	4.56E+00	2.04E+00	0	1.11E-10	0.003914
138	7.54E-02	2.06E+01	4.60E+00	2.06E+00	0	8.11E-11	0.003658
139	7.60E-02	2.07E+01	4.63E+00	2.07E+00	0	5.91E-11	0.003418
140	7.65E-02	2.09E+01	4.66E+00	2.09E+00	0	4.3E-11	0.003192
141	7.71E-02	2.10E+01	4.70E+00	2.10E+00	0	3.12E-11	0.002979
142	7.76E-02	2.12E+01	4.73E+00	2.12E+00	0	2.26E-11	0.00278
143	7.82E-02	2.13E+01	4.76E+00	2.13E+00	0	1.63E-11	0.002593
144	7.87E-02	2.15E+01	4.80E+00	2.15E+00	0	1.18E-11	0.002417
145	7.93E-02	2.16E+01	4.83E+00	2.16E+00	0	8.46E-12	0.002253
146	7.98E-02	2.18E+01	4.86E+00	2.18E+00	0	6.07E-12	0.002099
147	8.04E-02	2.19E+01	4.90E+00	2.19E+00	0	4.35E-12	0.001954
148	8.09E-02	2.21E+01	4.93E+00	2.21E+00	0	3.11E-12	0.001819
149	8.15E-02	2.22E+01	4.96E+00	2.22E+00	0	2.21E-12	0.001692
150	8.20E-02	2.24E+01	5.00E+00	2.24E+00	0	1.58E-12	0.001574
151	8.26E-02	2.25E+01	5.03E+00	2.25E+00	0	1.12E-12	0.001463
152	8.31E-02	2.27E+01	5.06E+00	2.27E+00	0	7.92E-13	0.001359
153	8.37E-02	2.28E+01	5.10E+00	2.28E+00	0	5.6E-13	0.001262
154	8.42E-02	2.30E+01	5.13E+00	2.30E+00	0	3.95E-13	0.001172
155	8.48E-02	2.31E+01	5.17E+00	2.31E+00	0	2.78E-13	0.001088

156	8.53E-02	2.33E+01	5.20E+00	2.33E+00	0	1.95E-13	0.001009
157	8.59E-02	2.34E+01	5.23E+00	2.34E+00	0	1.36E-13	0.000935
158	8.64E-02	2.36E+01	5.27E+00	2.36E+00	0	9.54E-14	0.000867
159	8.70E-02	2.37E+01	5.30E+00	2.37E+00	0	6.65E-14	0.000803
160	8.75E-02	2.39E+01	5.33E+00	2.39E+00	0	4.63E-14	0.000744
161	8.81E-02	2.40E+01	5.37E+00	2.40E+00	0	3.21E-14	0.000689
162	8.86E-02	2.42E+01	5.40E+00	2.42E+00	0	2.22E-14	0.000637
163	8.92E-02	2.43E+01	5.43E+00	2.43E+00	0	1.54E-14	0.000589
164	8.97E-02	2.45E+01	5.47E+00	2.45E+00	0	1.07E-14	0.000545
165	9.03E-02	2.46E+01	5.50E+00	2.46E+00	0	7.33E-15	0.000503
166	9.08E-02	2.48E+01	5.53E+00	2.48E+00	0	5E-15	0.000465
167	9.14E-02	2.49E+01	5.57E+00	2.49E+00	0	3.44E-15	0.000429
168	9.19E-02	2.51E+01	5.60E+00	2.51E+00	0	2.33E-15	0.000396
169	9.25E-02	2.52E+01	5.63E+00	2.52E+00	0	1.55E-15	0.000365
170	9.30E-02	2.54E+01	5.67E+00	2.54E+00	0	1.11E-15	0.000337
171	9.36E-02	2.55E+01	5.70E+00	2.55E+00	0	7.77E-16	0.000311
172	9.41E-02	2.57E+01	5.74E+00	2.57E+00	0	5.55E-16	0.000286
173	9.47E-02	2.58E+01	5.77E+00	2.58E+00	0	3.33E-16	0.000264
174	9.52E-02	2.60E+01	5.80E+00	2.60E+00	0	2.22E-16	0.000243
175	9.58E-02	2.61E+01	5.84E+00	2.61E+00	0	1.11E-16	0.000223
176	9.63E-02	2.63E+01	5.87E+00	2.63E+00	0	1.11E-16	0.000205
177	9.69E-02	2.64E+01	5.90E+00	2.64E+00	0	1.11E-16	0.000189
178	9.74E-02	2.66E+01	5.94E+00	2.66E+00	0	0	0.000174
179	9.80E-02	2.67E+01	5.97E+00	2.67E+00	0	0	0.000159
180	9.85E-02	2.69E+01	6.00E+00	2.69E+00	0	0	0.000146
181	9.91E-02	2.70E+01	6.04E+00	2.70E+00	0	0	0.000134
182	9.96E-02	2.72E+01	6.07E+00	2.72E+00	0	0	0.000123
183	1.00E-01	2.73E+01	6.10E+00	2.73E+00	0	0	0.000113
184	1.01E-01	2.75E+01	6.14E+00	2.75E+00	0	0	0.000104
185	1.01E-01	2.76E+01	6.17E+00	2.76E+00	0	0	9.49E-05
186	1.02E-01	2.78E+01	6.21E+00	2.78E+00	0	0	8.69E-05
187	1.02E-01	2.79E+01	6.24E+00	2.79E+00	0	0	7.96E-05
188	1.03E-01	2.81E+01	6.27E+00	2.81E+00	0	0	7.28E-05
189	1.03E-01	2.82E+01	6.31E+00	2.82E+00	0	0	6.66E-05
190	1.04E-01	2.84E+01	6.34E+00	2.84E+00	0	0	6.09E-05
191	1.05E-01	2.85E+01	6.37E+00	2.85E+00	0	0	5.57E-05
192	1.05E-01	2.87E+01	6.41E+00	2.87E+00	0	0	5.08E-05
193	1.06E-01	2.88E+01	6.44E+00	2.88E+00	0	0	4.64E-05
194	1.06E-01	2.90E+01	6.47E+00	2.90E+00	0	0	4.24E-05
195	1.07E-01	2.91E+01	6.51E+00	2.91E+00	0	0	3.87E-05
196	1.07E-01	2.93E+01	6.54E+00	2.93E+00	0	0	3.53E-05

197	1.08E-01	2.94E+01	6.57E+00	2.94E+00	0	0	3.21E-05
198	1.08E-01	2.96E+01	6.61E+00	2.96E+00	0	0	2.93E-05
199	1.09E-01	2.97E+01	6.64E+00	2.97E+00	0	0	2.67E-05
200	1.10E-01	2.99E+01	6.67E+00	2.99E+00	0	0	2.43E-05

2.3 FOR GEOMEMBRANE LANDFILL LINER MATERIAL

ne= 0.54
τ= 0.24
D_d= 2.59E-08
D_s= 6.22E-09
x_{max}= 3.34E-03

S.N.	x	C			C/C_0 (Concentration Ratio)		
		t=0.5	t=10	t=50	t=0.5	t=10	t=50
1	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1	1	1
2	1.67E-05	1.50E-01	3.35E-02	1.50E-02	0.832004	0.962167	0.983076
3	3.34E-05	3.00E-01	6.71E-02	3.00E-02	0.671373	0.924419	0.966159
4	5.02E-05	4.50E-01	1.01E-01	4.50E-02	0.524518	0.886841	0.949257
5	6.69E-05	6.00E-01	1.34E-01	6.00E-02	0.396144	0.849515	0.932378
6	8.36E-05	7.50E-01	1.68E-01	7.50E-02	0.288845	0.812524	0.91553
7	1.00E-04	9.00E-01	2.01E-01	9.00E-02	0.203092	0.775947	0.898719
8	1.17E-04	1.05E+00	2.35E-01	1.05E-01	0.137564	0.73986	0.881954
9	1.34E-04	1.20E+00	2.68E-01	1.20E-01	0.089686	0.704336	0.865242
10	1.51E-04	1.35E+00	3.02E-01	1.35E-01	0.056238	0.669447	0.848589
11	1.67E-04	1.50E+00	3.35E-01	1.50E-01	0.033895	0.635256	0.832004
12	1.84E-04	1.65E+00	3.69E-01	1.65E-01	0.019624	0.601826	0.815493
13	2.01E-04	1.80E+00	4.02E-01	1.80E-01	0.010909	0.569214	0.799064
14	2.17E-04	1.95E+00	4.36E-01	1.95E-01	0.005821	0.537469	0.782723
15	2.34E-04	2.10E+00	4.70E-01	2.10E-01	0.002979	0.50664	0.766478
16	2.51E-04	2.25E+00	5.03E-01	2.25E-01	0.001463	0.476767	0.750335
17	2.68E-04	2.40E+00	5.37E-01	2.40E-01	0.000689	0.447884	0.7343
18	2.84E-04	2.55E+00	5.70E-01	2.55E-01	0.000311	0.420023	0.71838
19	3.01E-04	2.70E+00	6.04E-01	2.70E-01	0.000134	0.393208	0.702582
20	3.18E-04	2.85E+00	6.37E-01	2.85E-01	5.57E-05	0.367456	0.686911
21	3.34E-04	3.00E+00	6.71E-01	3.00E-01	2.21E-05	0.342782	0.671373
22	3.51E-04	3.15E+00	7.04E-01	3.15E-01	8.4E-06	0.319193	0.655975
23	3.68E-04	3.30E+00	7.38E-01	3.30E-01	3.06E-06	0.296693	0.640721
24	3.85E-04	3.45E+00	7.71E-01	3.45E-01	1.07E-06	0.275279	0.625618
25	4.01E-04	3.60E+00	8.05E-01	3.60E-01	3.56E-07	0.254945	0.61067
26	4.18E-04	3.75E+00	8.39E-01	3.75E-01	1.14E-07	0.23568	0.595883
27	4.35E-04	3.90E+00	8.72E-01	3.90E-01	3.48E-08	0.217468	0.581261
28	4.52E-04	4.05E+00	9.06E-01	4.05E-01	1.02E-08	0.200291	0.56681
29	4.68E-04	4.20E+00	9.39E-01	4.20E-01	2.86E-09	0.184126	0.552532
30	4.85E-04	4.35E+00	9.73E-01	4.35E-01	7.66E-10	0.168948	0.538434
31	5.02E-04	4.50E+00	1.01E+00	4.50E-01	1.97E-10	0.154729	0.524518
32	5.18E-04	4.65E+00	1.04E+00	4.65E-01	4.83E-11	0.141437	0.510789

33	5.35E-04	4.80E+00	1.07E+00	4.80E-01	1.14E-11	0.129041	0.49725
34	5.52E-04	4.95E+00	1.11E+00	4.95E-01	2.55E-12	0.117506	0.483905
35	5.69E-04	5.10E+00	1.14E+00	5.10E-01	5.49E-13	0.106796	0.470756
36	5.85E-04	5.25E+00	1.17E+00	5.25E-01	1.13E-13	0.096875	0.457807
37	6.02E-04	5.40E+00	1.21E+00	5.40E-01	2.23E-14	0.087705	0.445061
38	6.19E-04	5.55E+00	1.24E+00	5.55E-01	4.22E-15	0.079248	0.432519
39	6.36E-04	5.70E+00	1.27E+00	5.70E-01	7.77E-16	0.071467	0.420184
40	6.52E-04	5.85E+00	1.31E+00	5.85E-01	1.11E-16	0.064323	0.408059
41	6.69E-04	6.00E+00	1.34E+00	6.00E-01	0	0.05778	0.396144
42	6.86E-04	6.15E+00	1.38E+00	6.15E-01	0	0.051799	0.384442
43	7.02E-04	6.30E+00	1.41E+00	6.30E-01	0	0.046345	0.372954
44	7.19E-04	6.45E+00	1.44E+00	6.45E-01	0	0.041383	0.36168
45	7.36E-04	6.60E+00	1.48E+00	6.60E-01	0	0.036879	0.350623
46	7.53E-04	6.75E+00	1.51E+00	6.75E-01	0	0.032799	0.339783
47	7.69E-04	6.90E+00	1.54E+00	6.90E-01	0	0.029112	0.32916
48	7.86E-04	7.05E+00	1.58E+00	7.05E-01	0	0.025787	0.318755
49	8.03E-04	7.20E+00	1.61E+00	7.20E-01	0	0.022796	0.308567
50	8.20E-04	7.35E+00	1.64E+00	7.35E-01	0	0.020111	0.298597
51	8.36E-04	7.50E+00	1.68E+00	7.50E-01	0	0.017706	0.288845
52	8.53E-04	7.65E+00	1.71E+00	7.65E-01	0	0.015557	0.279309
53	8.70E-04	7.80E+00	1.74E+00	7.80E-01	0	0.013641	0.26999
54	8.86E-04	7.95E+00	1.78E+00	7.95E-01	0	0.011937	0.260886
55	9.03E-04	8.10E+00	1.81E+00	8.10E-01	0	0.010424	0.251997
56	9.20E-04	8.25E+00	1.84E+00	8.25E-01	0	0.009084	0.243321
57	9.37E-04	8.40E+00	1.88E+00	8.40E-01	0	0.0079	0.234857
58	9.53E-04	8.55E+00	1.91E+00	8.55E-01	0	0.006856	0.226604
59	9.70E-04	8.70E+00	1.95E+00	8.70E-01	0	0.005938	0.21856
60	9.87E-04	8.85E+00	1.98E+00	8.85E-01	0	0.005132	0.210723
61	1.00E-03	9.00E+00	2.01E+00	9.00E-01	0	0.004427	0.203092
62	1.02E-03	9.15E+00	2.05E+00	9.15E-01	0	0.00381	0.195664
63	1.04E-03	9.30E+00	2.08E+00	9.30E-01	0	0.003272	0.188437
64	1.05E-03	9.45E+00	2.11E+00	9.45E-01	0	0.002805	0.181408
65	1.07E-03	9.60E+00	2.15E+00	9.60E-01	0	0.002399	0.174576
66	1.09E-03	9.75E+00	2.18E+00	9.75E-01	0	0.002048	0.167939
67	1.10E-03	9.90E+00	2.21E+00	9.90E-01	0	0.001744	0.161492
68	1.12E-03	1.01E+01	2.25E+00	1.01E+00	0	0.001482	0.155234
69	1.14E-03	1.02E+01	2.28E+00	1.02E+00	0	0.001257	0.149162
70	1.15E-03	1.04E+01	2.31E+00	1.04E+00	0	0.001064	0.143273
71	1.17E-03	1.05E+01	2.35E+00	1.05E+00	0	0.000899	0.137564
72	1.19E-03	1.07E+01	2.38E+00	1.07E+00	0	0.000758	0.132032
73	1.20E-03	1.08E+01	2.41E+00	1.08E+00	0	0.000637	0.126674

74	1.22E-03	1.10E+01	2.45E+00	1.10E+00	0	0.000535	0.121487
75	1.24E-03	1.11E+01	2.48E+00	1.11E+00	0	0.000448	0.116467
76	1.25E-03	1.13E+01	2.52E+00	1.13E+00	0	0.000374	0.111612
77	1.27E-03	1.14E+01	2.55E+00	1.14E+00	0	0.000312	0.106918
78	1.29E-03	1.16E+01	2.58E+00	1.16E+00	0	0.00026	0.102381
79	1.30E-03	1.17E+01	2.62E+00	1.17E+00	0	0.000216	0.098
80	1.32E-03	1.19E+01	2.65E+00	1.19E+00	0	0.000179	0.093769
81	1.34E-03	1.20E+01	2.68E+00	1.20E+00	0	0.000148	0.089686
82	1.35E-03	1.22E+01	2.72E+00	1.22E+00	0	0.000122	0.085747
83	1.37E-03	1.23E+01	2.75E+00	1.23E+00	0	0.0001	0.08195
84	1.39E-03	1.25E+01	2.78E+00	1.25E+00	0	8.25E-05	0.07829
85	1.40E-03	1.26E+01	2.82E+00	1.26E+00	0	6.76E-05	0.074764
86	1.42E-03	1.28E+01	2.85E+00	1.28E+00	0	5.53E-05	0.071369
87	1.44E-03	1.29E+01	2.88E+00	1.29E+00	0	4.52E-05	0.068101
88	1.46E-03	1.31E+01	2.92E+00	1.31E+00	0	3.68E-05	0.064958
89	1.47E-03	1.32E+01	2.95E+00	1.32E+00	0	2.99E-05	0.061935
90	1.49E-03	1.34E+01	2.99E+00	1.34E+00	0	2.43E-05	0.059029
91	1.51E-03	1.35E+01	3.02E+00	1.35E+00	0	1.96E-05	0.056238
92	1.52E-03	1.37E+01	3.05E+00	1.37E+00	0	1.59E-05	0.053557
93	1.54E-03	1.38E+01	3.09E+00	1.38E+00	0	1.28E-05	0.050984
94	1.56E-03	1.40E+01	3.12E+00	1.40E+00	0	1.03E-05	0.048515
95	1.57E-03	1.41E+01	3.15E+00	1.41E+00	0	8.24E-06	0.046148
96	1.59E-03	1.43E+01	3.19E+00	1.43E+00	0	6.6E-06	0.043878
97	1.61E-03	1.44E+01	3.22E+00	1.44E+00	0	5.27E-06	0.041703
98	1.62E-03	1.46E+01	3.25E+00	1.46E+00	0	4.2E-06	0.039621
99	1.64E-03	1.47E+01	3.29E+00	1.47E+00	0	3.34E-06	0.037627
100	1.66E-03	1.49E+01	3.32E+00	1.49E+00	0	2.65E-06	0.035719
101	1.67E-03	1.50E+01	3.35E+00	1.50E+00	0	2.1E-06	0.033895
102	1.69E-03	1.52E+01	3.39E+00	1.52E+00	0	1.66E-06	0.032151
103	1.71E-03	1.53E+01	3.42E+00	1.53E+00	0	1.31E-06	0.030484
104	1.72E-03	1.55E+01	3.45E+00	1.55E+00	0	1.03E-06	0.028892
105	1.74E-03	1.56E+01	3.49E+00	1.56E+00	0	8.09E-07	0.027372
106	1.76E-03	1.58E+01	3.52E+00	1.58E+00	0	6.34E-07	0.025921
107	1.77E-03	1.59E+01	3.56E+00	1.59E+00	0	4.96E-07	0.024538
108	1.79E-03	1.61E+01	3.59E+00	1.61E+00	0	3.87E-07	0.023219
109	1.81E-03	1.62E+01	3.62E+00	1.62E+00	0	3.01E-07	0.021962
110	1.82E-03	1.64E+01	3.66E+00	1.64E+00	0	2.34E-07	0.020765
111	1.84E-03	1.65E+01	3.69E+00	1.65E+00	0	1.81E-07	0.019624
112	1.86E-03	1.67E+01	3.72E+00	1.67E+00	0	1.4E-07	0.018539
113	1.87E-03	1.68E+01	3.76E+00	1.68E+00	0	1.08E-07	0.017507
114	1.89E-03	1.70E+01	3.79E+00	1.70E+00	0	8.32E-08	0.016526

115	1.91E-03	1.71E+01	3.82E+00	1.71E+00	0	6.39E-08	0.015593
116	1.92E-03	1.73E+01	3.86E+00	1.73E+00	0	4.9E-08	0.014707
117	1.94E-03	1.74E+01	3.89E+00	1.74E+00	0	3.75E-08	0.013865
118	1.96E-03	1.76E+01	3.92E+00	1.76E+00	0	2.86E-08	0.013067
119	1.97E-03	1.77E+01	3.96E+00	1.77E+00	0	2.18E-08	0.012309
120	1.99E-03	1.79E+01	3.99E+00	1.79E+00	0	1.66E-08	0.011591
121	2.01E-03	1.80E+01	4.02E+00	1.80E+00	0	1.25E-08	0.010909
122	2.02E-03	1.82E+01	4.06E+00	1.82E+00	0	9.49E-09	0.010264
123	2.04E-03	1.83E+01	4.09E+00	1.83E+00	0	7.17E-09	0.009653
124	2.06E-03	1.85E+01	4.13E+00	1.85E+00	0	5.4E-09	0.009075
125	2.07E-03	1.86E+01	4.16E+00	1.86E+00	0	4.06E-09	0.008528
126	2.09E-03	1.88E+01	4.19E+00	1.88E+00	0	3.04E-09	0.00801
127	2.11E-03	1.89E+01	4.23E+00	1.89E+00	0	2.28E-09	0.007521
128	2.12E-03	1.91E+01	4.26E+00	1.91E+00	0	1.7E-09	0.007058
129	2.14E-03	1.92E+01	4.29E+00	1.92E+00	0	1.27E-09	0.006622
130	2.16E-03	1.94E+01	4.33E+00	1.94E+00	0	9.42E-10	0.00621
131	2.17E-03	1.95E+01	4.36E+00	1.95E+00	0	6.98E-10	0.005821
132	2.19E-03	1.97E+01	4.39E+00	1.97E+00	0	5.17E-10	0.005454
133	2.21E-03	1.98E+01	4.43E+00	1.98E+00	0	3.82E-10	0.005108
134	2.22E-03	2.00E+01	4.46E+00	2.00E+00	0	2.81E-10	0.004782
135	2.24E-03	2.01E+01	4.49E+00	2.01E+00	0	2.07E-10	0.004475
136	2.26E-03	2.03E+01	4.53E+00	2.03E+00	0	1.52E-10	0.004186
137	2.27E-03	2.04E+01	4.56E+00	2.04E+00	0	1.11E-10	0.003914
138	2.29E-03	2.06E+01	4.60E+00	2.06E+00	0	8.11E-11	0.003658
139	2.31E-03	2.07E+01	4.63E+00	2.07E+00	0	5.91E-11	0.003418
140	2.32E-03	2.09E+01	4.66E+00	2.09E+00	0	4.3E-11	0.003192
141	2.34E-03	2.10E+01	4.70E+00	2.10E+00	0	3.12E-11	0.002979
142	2.36E-03	2.12E+01	4.73E+00	2.12E+00	0	2.26E-11	0.00278
143	2.37E-03	2.13E+01	4.76E+00	2.13E+00	0	1.63E-11	0.002593
144	2.39E-03	2.15E+01	4.80E+00	2.15E+00	0	1.18E-11	0.002417
145	2.41E-03	2.16E+01	4.83E+00	2.16E+00	0	8.46E-12	0.002253
146	2.43E-03	2.18E+01	4.86E+00	2.18E+00	0	6.07E-12	0.002099
147	2.44E-03	2.19E+01	4.90E+00	2.19E+00	0	4.35E-12	0.001954
148	2.46E-03	2.21E+01	4.93E+00	2.21E+00	0	3.11E-12	0.001819
149	2.48E-03	2.22E+01	4.96E+00	2.22E+00	0	2.21E-12	0.001692
150	2.49E-03	2.24E+01	5.00E+00	2.24E+00	0	1.58E-12	0.001574
151	2.51E-03	2.25E+01	5.03E+00	2.25E+00	0	1.12E-12	0.001463
152	2.53E-03	2.27E+01	5.06E+00	2.27E+00	0	7.92E-13	0.001359
153	2.54E-03	2.28E+01	5.10E+00	2.28E+00	0	5.6E-13	0.001262
154	2.56E-03	2.30E+01	5.13E+00	2.30E+00	0	3.95E-13	0.001172
155	2.58E-03	2.31E+01	5.17E+00	2.31E+00	0	2.78E-13	0.001088

156	2.59E-03	2.33E+01	5.20E+00	2.33E+00	0	1.95E-13	0.001009
157	2.61E-03	2.34E+01	5.23E+00	2.34E+00	0	1.36E-13	0.000935
158	2.63E-03	2.36E+01	5.27E+00	2.36E+00	0	9.54E-14	0.000867
159	2.64E-03	2.37E+01	5.30E+00	2.37E+00	0	6.65E-14	0.000803
160	2.66E-03	2.39E+01	5.33E+00	2.39E+00	0	4.63E-14	0.000744
161	2.68E-03	2.40E+01	5.37E+00	2.40E+00	0	3.21E-14	0.000689
162	2.69E-03	2.42E+01	5.40E+00	2.42E+00	0	2.22E-14	0.000637
163	2.71E-03	2.43E+01	5.43E+00	2.43E+00	0	1.54E-14	0.000589
164	2.73E-03	2.45E+01	5.47E+00	2.45E+00	0	1.07E-14	0.000545
165	2.74E-03	2.46E+01	5.50E+00	2.46E+00	0	7.33E-15	0.000503
166	2.76E-03	2.48E+01	5.53E+00	2.48E+00	0	5E-15	0.000465
167	2.78E-03	2.49E+01	5.57E+00	2.49E+00	0	3.44E-15	0.000429
168	2.79E-03	2.51E+01	5.60E+00	2.51E+00	0	2.33E-15	0.000396
169	2.81E-03	2.52E+01	5.63E+00	2.52E+00	0	1.55E-15	0.000365
170	2.83E-03	2.54E+01	5.67E+00	2.54E+00	0	1.11E-15	0.000337
171	2.84E-03	2.55E+01	5.70E+00	2.55E+00	0	7.77E-16	0.000311
172	2.86E-03	2.57E+01	5.74E+00	2.57E+00	0	5.55E-16	0.000286
173	2.88E-03	2.58E+01	5.77E+00	2.58E+00	0	3.33E-16	0.000264
174	2.89E-03	2.60E+01	5.80E+00	2.60E+00	0	2.22E-16	0.000243
175	2.91E-03	2.61E+01	5.84E+00	2.61E+00	0	1.11E-16	0.000223
176	2.93E-03	2.63E+01	5.87E+00	2.63E+00	0	1.11E-16	0.000205
177	2.94E-03	2.64E+01	5.90E+00	2.64E+00	0	1.11E-16	0.000189
178	2.96E-03	2.66E+01	5.94E+00	2.66E+00	0	0	0.000174
179	2.98E-03	2.67E+01	5.97E+00	2.67E+00	0	0	0.000159
180	2.99E-03	2.69E+01	6.00E+00	2.69E+00	0	0	0.000146
181	3.01E-03	2.70E+01	6.04E+00	2.70E+00	0	0	0.000134
182	3.03E-03	2.72E+01	6.07E+00	2.72E+00	0	0	0.000123
183	3.04E-03	2.73E+01	6.10E+00	2.73E+00	0	0	0.000113
184	3.06E-03	2.75E+01	6.14E+00	2.75E+00	0	0	0.000104
185	3.08E-03	2.76E+01	6.17E+00	2.76E+00	0	0	9.49E-05
186	3.09E-03	2.78E+01	6.21E+00	2.78E+00	0	0	8.69E-05
187	3.11E-03	2.79E+01	6.24E+00	2.79E+00	0	0	7.96E-05
188	3.13E-03	2.81E+01	6.27E+00	2.81E+00	0	0	7.28E-05
189	3.14E-03	2.82E+01	6.31E+00	2.82E+00	0	0	6.66E-05
190	3.16E-03	2.84E+01	6.34E+00	2.84E+00	0	0	6.09E-05
191	3.18E-03	2.85E+01	6.37E+00	2.85E+00	0	0	5.57E-05
192	3.19E-03	2.87E+01	6.41E+00	2.87E+00	0	0	5.08E-05
193	3.21E-03	2.88E+01	6.44E+00	2.88E+00	0	0	4.64E-05
194	3.23E-03	2.90E+01	6.47E+00	2.90E+00	0	0	4.24E-05
195	3.24E-03	2.91E+01	6.51E+00	2.91E+00	0	0	3.87E-05
196	3.26E-03	2.93E+01	6.54E+00	2.93E+00	0	0	3.53E-05

197	3.28E-03	2.94E+01	6.57E+00	2.94E+00	0	0	3.21E-05
198	3.29E-03	2.96E+01	6.61E+00	2.96E+00	0	0	2.93E-05
199	3.31E-03	2.97E+01	6.64E+00	2.97E+00	0	0	2.67E-05
200	3.33E-03	2.99E+01	6.67E+00	2.99E+00	0	0	2.43E-05