ABSTRACT

Introduction

Uninterrupted exploitation of natural resources and the exploding population have resulted in degradation of quality of life in general. To meet the necessities of expanding millions, it became essential to produce more. As a consequence, rapid industrialization has become imperative. Industrial activity is necessary for the socio-economic progress of the country. Setting up of industries without proper waste treatment and disposal plants, especially in developing countries are causing irreparable damage to the environment. In the recent years environmental pollution control boards have imposed restriction on disposal of wastes in rivers to prevent pollution because river water is most commonly used for human consumption. To escape from these restrictions, which require costly treatment of waste water there is a tendency to dispose of waste water on ground.

Clay liners are often used as parts of waste contaminant systems in waste disposal sites to inhibit the transport of liquid contaminants into ground water aquifers. Because of low hydraulic conductivity, in-situ and re-compacted clayey soils are used as impervious liners for landfills and waste storage impoundments. Additionally, clayey soils owing to their charged surface characteristics can interact with the contaminants in the leachate and retain them, thereby reducing the contaminant load polluting the ground water. Liner system is a significant component part of waste disposal system.

Background Information

Hosney and Rowe (2013) formed a test cover comprising of three different needle-punched geosynthetic clay liner (GCL) products and covered with up to 1 m of cover soil. Gravelly sand was built over arsenic-rich tailings at a former gold mine in Nova Scotia, Canada, and evaluated the performance of the geosynthetic clay liners under local climatic conditions. Wuana et.al (2010) demonstrated that depending on the
nature of the chelants, washing efficiencies varied in the order: EDTA > citric acid > tartaric acid with metal extraction yields typically following the sequence Cu > Ni > Zn > Cd > Pb. Gates et al (2009) observed that traditional specification methods which define bentonite quality or performance, i.e., swell index, fluid loss and permeability with deionised water, are essentially manufacturing quality control tests and should not be considered the only criteria for specifying a GCL. Lange et al (2007) considered the potential for Geo-synthetic Clay Liners (GCLs) to serve as a barrier in holding ponds in which Acidic Rock Drainage (ARD) waters that have been treated with lime (termed ‘TARD’) and still possess some dissolved metal concentration (e.g. Zn, Cd), require a minimum retention time. Jae-Myung and Charles D (2005) conducted Swell Index (SI) and Solution Retention Capacity (SRC) on samples of different quality bentonites taken from two Geo-synthetic Clay Liners using de-ionized water (DIW) and chemical solutions containing from 5 to 500 mM CaCl₂.

A liner has a main purpose of preventing/minimizing the migration of fluids (mainly leachate) directly into the underlying subsurface during both the active disposal period, typically 10 to 20 years as well as the inactive, or post-closure period. Daniel and Wu (1993) and Rowe et al. (1995) stated that natural clay liners (e.g., aquitards and aquicludes) and engineered liners are types of liners which are used in waste disposal systems around the world. Natural liners have the following attributes which make them suitable as liners of waste containment systems: (1) they contain significant amounts of clay minerals and have hydraulic conductivities less than or equal to $1 \times 10^{-7}$ cm/s; (2) they typically serve as a back-up to engineering liners, but occasionally (for old landfills or, where regulations allow, for new landfills), a natural liner may represent the only liner at a waste disposal facility. Soils that are rich in clay minerals are usually used for constructing compacted liners because they have low hydraulic conductivity which is required to be less than $1 \times 10^{-7}$ cm/s (Bowders and Daniel (1987); Benson and Daniel (1990); Benson and Trast, (1995)).

Compacted clay liners are an integral component of lining systems used for municipal and hazardous waste landfills. Because the primary purpose of a compacted clay liner is to impede the flow of fluids, the most significant factor affecting its performance is hydraulic conductivity (Bowders and Daniel (1987); Benson and Daniel (1990)). Soils rich in clay minerals are used for constructing compacted soil liners because they
have low hydraulic conductivity and can attenuate inorganic contaminants. Most regulatory agencies in the United States require that the hydraulic conductivity of clay liners be less than or equal to $1 \times 10^{-9}$ m/s. Although the hydraulic conductivity of clayey soils is normally considered to be low, the hydraulic conductivity of compacted clays can vary tremendously depending on the soil composition and the conditions under which they are compacted (Lambe 1954; Mitchell et al. 1965; Garcia-Bengochea et al. 1979; Acar and Oliveri 1990; Benson et al. 1994). For example, Benson and Daniel (1990) reported that the hydraulic conductivity of a highly plastic clay from the Gulf Coast of Texas varied by six orders of magnitude depending on the moulding water content and degree of compaction. Smaller, yet significant changes in hydraulic conductivity also occur as a consequence of variations in soil composition (Benson et al. 1994). Liners are exposed to various chemical, biological, and physical processes due to leachate production and other chemical compound generation during the biodegradation process, their in-situ geotechnical properties might be different from the ones estimated in laboratories. Further, the steady state condition is attained when the soil is completely saturated in order to estimate the permeability.

The various observations as seen above by different researchers underline the importance of use clayey soils for control of pollutant migration. However, a comprehensive, coherent understanding based on the phenomenological model is not yet available for use in a practical situation. Accordingly the cardinal aim of the present study is focussed on characterising the behaviour of regional soils which are usually encountered in the region in conjunction with inorganic chemicals predominantly found in plating/tanning industries.

**Basic considerations**

The main task in the design and construction of impermeable liners in landfills is to block the migration of pollutants to the groundwater systems or to reduce its rate to a reasonable amount. That is why environmental regulations force governments to construct engineered waste dumps for waste management purposes. These liners are exposed to various types of chemical, biological, and physical processes and are affected by the leachate which is produced from decomposition of waste materials
accompanying methane gas. The leachate includes a lot of components such as water and different types of salts. For this reason, the geotechnical characteristics of clay liners which are evaluated in laboratories using distilled water or tap water might be far different from the representative sample of the in-situ conditions. There are some evidences regarding the effect of these salts on the physical and mechanical properties of clay barriers which could affect the long-term performance of these liners. Since the main criterion for impermeable bottom liners in landfills is their hydraulic conductivity, the increase of this parameter could have a considerable environmental impact. The present work embraces the results of a comprehensive study on Geotechnical characteristics in conjunction with water as compared to the pollutants in different proportions. The inorganic salts, considered include NaCl, CaCl$_2$ and MgCl$_2$ on some geotechnical properties of a common used clay soil in impermeable bottom adding different percentage of this special clay mineral, 3 and 5 percent, on these properties was investigated. Laboratory tests like liquid limit, compaction, 1D consolidation and free swell tests were performed for this purpose. Results indicated that all of these salts could have a considerable effect on the geotechnical properties of the mixtures. The main reason of such effects is the changes which occur in diffuse double layer of clay particles.

The liquid limits are usually conducted for soil fraction passing 425 microns. The values thus obtained may not be true representation of the entire soil. The presence of coarse particles only dilutes the physcio-chemical potential of the soil proportionately (Srinivasa Muthy et al (1987). Accordingly the modified liquid limit ($w_{\text{lm}}$) and modified plasticity index ($I_{\text{pm}}$) are defined to analyze the test results. The modified liquid limit is defined as $w_{\text{lm}} = w_l \times F/100$ and the modified plasticity index $I_{\text{pm}}=I_p \times F/100$ where F is fraction passing through 425 microns. These parameters are found to have coherent relationships with basic and engineering properties of soils tested with water and pollutants.

The EPA requires that soil liners be built so that the hydraulic conductivity is equal to or less than $1 \times 10^{-7}$ cm/s. To meet this requirement, certain characteristics of soil material should be met. First, the soils should contain at least 15–20% of silt or clay sized material ($<0.075$ mm). Secondly, the Plasticity Index (PI) should be greater than 10%. Soils with very high PI, greater than 30–40%, are sticky and are difficult to
work with. Also high PI soils form hard clumps when the soils are dry and difficult to break down during compaction. Thirdly, the coarser fragments should be screened to no more than about 10% gravel-size particles.

**Scope of the Study**

The release and migration of hazardous constituents from uncontrolled disposal of tannery waste sludge can cause contamination of subsurface soil and groundwater, posing a significant risk to public health and the environment. To contain such uncontrolled release and migration of hazardous contaminants into the environment, engineered waste landfills with liner systems consisting of low permeability materials need to be implemented. A major constraint to the development of engineered landfills in Tirupati, India, is the high cost of synthetic liners and its scarcity in the local markets, thus there is a need for other readily available source materials for landfill liners, preferably, soils of clayey origin. The selection of soils for liners should be based on their permeability and capacity to retain undesirable constituents from leaching out from the wastes. The retention capacity of a soil for contaminants depends on the soil minerals, amorphous constituents, soil organic matter, and type and amount of the contaminants.

The aim of the present investigation is to establish the characteristics of uncontaminated soils and to study the effects of modeled solutions, simulated to represent the effluent characteristics, on basic properties of soils. An attempt to determine functional relationships between basic properties and engineering properties has also been made. The possible approach to predict the time of travel per unit distance has been examined.

**Study Area**

The study area is limited to Tirupati region of Andhra Pradesh state (India) approximately enclosed between 12° 37’ - 14° 8’ north latitudes and 78° 3’ - 79° 55’ east longitudes.
Experimental Investigation

The experimental investigation is split into two series. In the first series of experiments three sols of Clay with High Compressibility (CH) were considered with inherent variations in grain size and plasticity characteristics. The samples identified are predominantly clayey with plasticity index ranging from 27-44, and the percentage passing 425 microns range from 85 to 96. The inorganic chemicals used in the present study include calcium, chromium, sodium, iron and zinc, which are normally present in plating industry located in the vicinity of Tirupati region. The basic soil properties such as liquid limit, plastic limit, and compaction and permeability characteristics were determined using water and synthesized solutions to represent the effluent composition. In order to have overall control over the properties of chemical constituents; the solutions are spiked to give rise to mono and mixed properties. The chemical mixed mono and mixed solutions are permeated through soils in concentrations usually present in local industrial effluents. The basic properties of soils such as liquid limit, plastic limit and compaction tests are determined using molding fluid as water and spiked solutions with varying concentrations. This has been done with a view to understand the effects of contaminants on the basic and engineering properties when water polluted with different proportions of chemicals is used in the construction of clay blankets or liner systems.

The soils have been compacted according to light compaction for all the soil samples varying the percentage of chemical contents. The soil specimens for oedometer test have been extracted from the soil samples thus soaked and placed in the oedometer for further testing. After placing the specimens in oedometer normal water was allowed to permeate through the samples by keeping constant head in the oedometer. After ensuring continuous flow of water and hydraulic conductivity, the water in the tank is replaced by the spiked solution. The nominal load of 25 kN/m$^2$ is then placed on the soil sample and the solution at the exit is collected for further analysis to determine atomic absorption spectrometer. The permeability values have been determined from the observations of compression readings with time. Atomic absorption spectrometer tests have been conducted to assess the composition of the fluids after permeating through the soil samples. The results have led to the
observation that depending on the initial composition of the soil there is a possibility of the pollutants getting leached or the pollutants getting attenuated.

Soil from Perumalla Palli attenuates sodium to a smaller degree when it is permeated through as a mono solution. Soil from Auto Nagar attenuates Sodium to a relatively higher degree when it is permeated through as a mono solution. Calcium is attenuated to a greater degree by all soils. Iron is leached out of all soils. Zinc and Chromium are attenuated to significant extent considering the concentration levels attempted in the present study.

In the second series of experimental investigation, five different soil samples have been selected. The samples tested are classified as Clayey Sand (SC) to Clay with High Compressibility (CH). The values of liquid limit range from 30-55. The Plasticity Index ranges from 9-49, showing wide range. An attempt has been made to examine the possibility of establishing the functional relationships between basic properties and engineering properties of five different soils with water as well as synthesized solutions using the pollutants. The experimental investigation has provided well defined inter-relationships. Guided by these observations, it has been further explored to propose a model to predict the pollutant migration by conducting permeability tests. The permeability tests conducted considered the compact specimens using water as pore fluid at respective moisture contents as also with synthesized solutions modeled to simulate the possible effluent characteristics. Scanning Electron Microscope and Energy Dispersion Spectroscopy studies have been conducted on soil samples before and after subjecting to the pollutants in order to reinforce the observations made. The permeability tests indicated that the values of coefficient of permeability depend on the current void ratio and the void ratio corresponding to liquid limit. This phenomenological model helps calculating the time involved in a particular pollutant for travelling, a unit distance. The practical consequence of this observation is that the time of travel needed for a particular clay liner to prevent pollutant migration can be estimated and accordingly the decision to consider the redemption of the clay liner can be taken.
Organization of the Thesis

The present work is divided into 6 chapters for facility of presentation. The contents of each chapter are summarized as follows:

Chapter 1 deals with introduction bringing out the scope of the present investigation. Background information is provided in Chapter 2 dealing with relevant research works carried out relating to the present study. Chapter 3 deals with basic considerations and details of experimental investigation. An analysis of test results is presented in Chapter 4. Proposed approach for prediction of permeability characteristics and time of travel for pollutant migration is brought out in Chapter 5. The summary and concluding remarks together with further scope are presented in Chapter 6.