Viewing Natural Clay Soils as Replacements for Synthetic Materials

Emmanuel Emem-Obong Agbenyeku, Edison Muzenda, and Innocent Mandla Msibi

Abstract**—**Substitutes either as partial or total replacement for synthetic materials used in the bottom lining of hot leachate ponds has been addressed by a few researchers in ongoing times. The pertinence of this synthetic replacement by other naturally occurring materials cannot be over emphasized. From the considerations in this study, the utilization of selected treated or parent clay/clayey soils as hydraulic barriers and attenuation profiles is seen as a major option to be exploited. This option most importantly, has potentials for use particularly in underdeveloped countries for: the reduction in cost of leachate pond construction as well as the reduction in risk of subsoil and groundwater contamination. The decomposition of disposed solid waste generates leachate and the impact of heated leachate brines on synthetic liner in ponds is of key concern to waste containment experts. This paper therefore addressed a few physical, chemical and hydraulic properties common to natural soils mainly for use as compacted clay liners (CCLs). Underdeveloped nations have the option to use this type of liner, on account that; before incorporation into existing systems, several chemical, mechanical and leachate compactibility tests must be carried out on the liners. Tests for soil and water composition, permeability, plasticity, X-ray diffraction and leachate analysis are a few necessary investigations prior the utilization of soil barriers in heated ponds containing leachate brines and leachate in general.

Keywords**—**Hydraulic barriers, Leachate, Synthetic materials, Contamination, Compacted clay liners

I. INTRODUCTION

FOR optimum performance, the functionality of a suitable hot pond lining system is totally necessary to its service life. A properly functioning hot pond liner system entails a barrier with sufficient thermal separation/resistance and water tightness. Concurrently, the liner should hinder the percolation of contaminants into underlying aquifers or other underground water reserves. The utilization of plastic/synthetic materials i.e., geomembranes (GMs) and polyethylene (PE) have been in use over time. Their successes as reported by [1] have been recorded on several occasions over small scale uses in containing leachate in heated ponds. However, in larger hot ponds such as reactor systems for electricity generation, synthetic lining materials gravely increase the cost of running the ponds by over or about 30%. An option to reducing the cost incurred from the use of synthetic lining systems in large hot ponds could be the partial or total replacements of liners with naturally occurring or treated parent clay/clayey soils. This is particularly true for developing nations and in regions where such parent materials abound. Nevertheless, geoenvironmental experts are charged with the responsibilities of investigating such locally available parent or modified materials for their environmental impacts and containment properties as a whole. Cost reduction could be further achieved via the utilization of cheap plastic materials to form the basis for a composite lining system *e.g.*, PE sandwiched by naturally occurring treated or parent clay/clayey soils. The system of a composite barrier from cheap waste materials have shown good results after modifications and as reported by [2] their net effectiveness increases the possibility of constructing ponds at the lowest possible cost as compared to those constructed entirely out of synthetic membranes. Damages to synthetic membranes used as hydraulic barriers and for other purposes in containment facilities are inevitable. Often times, synthetic membranes may be defected from fabrication, installation or over time due to exposure to the elements *e.g.*, ultraviolet radiation (UV). As such, the incorporation of natural clay soils as part of a geo-composite unit becomes an efficient and economic design for a contaminant barrier. The liner as stated by [1] may be composed of a polyethylene film of low density (PLDE) manufactured locally and placed between two compacted locally available clay layers to form a composite barrier. Nevertheless, it should be noted that the PE film have certain demerits such as; low bond reliability, thinness, rigidity, low resistance to wrinkling and degradation by the elements [3].

The first ever application of a geosynthetic clay liner (GCL) in a hot pond as reported by [4] was done at the University of Texas, El Paso. A layer of plastic initially served as the impermeable barrier and comprised of a polyester membrane covered with polyvinyl-chloride (PVC). The layer formed part of a double liner with a secondary confinement of chloro-sulfonated polyethylene resin (CSPE) membrane. The decision to incorporate GCL barrier in the design and construction process was mostly due to its cost effectiveness and ease of installation. The GCL failed after two years and the degradation of the material were ascribed to UV radiation and manufacturing defects. Investigations however, revealed the premature failure to have most probably resulted from the loss of elasticity- caused by hot leachate brines and direct exposure to acidic solutions [4]. CCLs are difficult to construct and repair when duly required. They are relatively thick and are highly prone to desiccative effects and subsequent cracking

Emmanuel Emem-Obong Agbenyeku is a research student at the University of Johannesburg, South Africa (phone: +27 11 559 6396; e-mail: emmaa@uj.ac.za).

Edison Muzenda is Head of Environmental and Process Systems Engineering Research Unit, Department of Chemical Engineering, University of Johannesburg, South Africa (phone: +27 11 559 6817; e-mail: emuzenda@uj.ac.za).

Innocent Mandla Msibi is Executive Director of the Research and Innovation Division, University of Johannesburg, South Africa (phone: +27 11 559 6280; e-mail: mimsibi@uj.ac.za).

http://dx.doi.org/10.15242/IIE.E1214064

particularly, in dry and high temperature regions. However as recorded by [5] comparatively, they possess certain merits over geosynthetics i.e., they are resistant to damage from puncture, they offer extended contaminant retention periods, they have good leachate contaminant attenuation capacity and their cost is generally lesser due to in-situ availability. This study therefore draws attention to certain physical, chemical and hydraulic properties common to natural soils mainly for use as CCLs. It translates to the functional geoenvironmental design and construction of effective clay mineral barriers; which when properly executed can be harnessed by underdeveloped nations as an essential component of a containment facility for heated leachate ponds towards a sustained cost reducing option.

II. Factors Influencing Soil Barriers In Heated Leachate Containment Facilities

Clay/mineral liners

The geoenvironmental design and construction of functional, environmental friendly and cost effective mineral liners for hot ponds requires the analysis of multiple factors such as; the infiltration of contaminants through defected barrier components, the migration of contaminants *e.g.*, brine (salts) and acids towards regions with consequential impacts as well as heat padding. The optional application of mineral barriers as cost saving agents involves the investigation of factors such as consolidation and volume change, deformation and volumetric stability of soils, percolation and transportation of fluids, particles and soil geothermal energy etc. The possible presence of pore-water pressures, difference in composition and adsorbent field forces on particle surfaces and among particles and the effect of chemical and heat gradients on the state of energy of the pore fluid from point to point are a few considerations of note. These effects influence the analysis of fluid transport and pressure in the soil as was reported by [6]. Therefore, suitable natural occurring earth-based materials utilized as partial or total replacements for polythene-based liners may include: (i) mixtures of natural treated or parent clay/clayey soils of large percentage fines plus coarse-grained material with a significant amount of fine fractions (ii) modified and chemically stabilized soils, like clay with silt, and (iii) soil mixture *e.g.*, with sand and sodium bentonite.

Bentonite is particularly suitable as a sealing material based on its self-healing characteristics. Its high montmorillonite content, associated capacity for swelling and low coefficients of permeability, and diffusion makes it highly appreciable as a barrier composition for containment systems. However, natural or soda-enhanced sodium bentonite as recorded by [7] is considered more suitable due to its potent gel formation (increased swelling tendency) than other bentonite mixtures *e.g.*, calcium bentonites. From existing literature, zeolites have been found to enhance workability, reduce weight and moderate water content while allowing for slower drying when blended with clayey soils. This mixture as recorded by [6] possesses potentials for reduced desiccative and cracking effects in soils. While aluminosilicate minerals were reported to improve the reduction of contaminant diffusion through natural parent or treated clayey barriers and serve as heat storage of solar radiation. Geoenvironmental and geotechnical investigations are vital in the determination of key elemental and mechanical properties of locally available earth materials. Thus, the permeability and consolidation coefficients, leachatability, chemical compactibility and durability etc., of soil liners can be ascertained in the design and construction of containment systems. Certain parent soils found at developing sites may be unfit for an intended construction purpose. As in the case of landfills, some soils may not entirely be suitable as hydraulic barriers or contaminant attenuation profiles. Such soils may have their properties improved by the addition of wastes ashes [8]. Soils with low plasticity can be blended with bentonites containing argillaceous minerals to improve their engineering characteristics as duly desired.

For hot leachate containment soil liners, particularly in completely drained soils, increased temperature/radiation causes a decrease in volume of the barrier material [6]. As such, in order to reduce the influence of heat induced soil changes- swelling and dispersion potentials of soils, heating is used as an effective stabilization method (thermal stabilization) [9]. Fissures and joints may occur from both the effects of shrinkage cracks during desiccation and generate cracks due to subaqueous syneresis. Syneresis was defined by [9] as a term which describes the process of spontaneous contraction of colloidal aggregates and dense gels without evaporating the constituent pore fluid. In literature, syneresis is rarely discussed from a geoenvironmental or geotechnical perspective. Nevertheless, it is a highly complex process that occurs due to the domination of Interparticle attractive forces of clay particles to produce jointly packed aggregates with fissures between them. This process as documented by [6] and [10] varies as a function of the nature and concentration of the components of the soil and temperature.

Permeability/Percolation Tests and Migration Control

Fluid flows through porous soil media under hydraulic heads. This is a specific measurement of fluid pressure above a reference point. To determine a hydraulic gradient between two or more points, the hydraulic head is used. Permeability may be explained as the tendency of a material (i.e., in this case, soil) to permit the percolation of fluids. The measure of the degree to which a fluid percolates through an earth material under a given hydraulic gradient is termed its coefficient of permeability. With respect to fluid flow in a leachate pond, it can be assumed that fluid transport through a soil barrier is governed by Darcy's law. This directly knots the proportional relationship between the volumetric flow rate Q, and hydraulic gradient i, i.e., $Q = kiA$. Here, the k- becomes the permeability coefficient (hydraulic conductivity) and A- the cross-sectional area in the path of the fluid flow. Whereas, permeability coefficient is a direct function of: (a) the fluid characteristics and (b) the structural arrangement of the porous media (clayey soil barrier). In the case of wetted and/or saturated clay barriers, this law also applies. However, it can be deviated due to influencing factors such as; chemical concentrations, particle movement and effects of electro kinetics on the materials in contact [6]. It has been recorded from previous studies that a change in gradient type results in a change in the flow of fluid. Also, the flow of water under temperature slopes as in the case of a heated pond is vital in partly saturated soils. Hence, this phenomenon is known as thermo-osmosis. Temperature alterations may trigger fluctuations in the flow of certain elements *e.g.*, air and water and, thus, leads to volumetric changes within the soil media. In a non-saturated soil media, one-dimensional flow as documented in the works of [9] must be formulated to integrate temperature slopes, as well as transport of liquid vapor. This can have considerable influence in non-isothermal scenarios. Heat-induced diffusion of electrolytes- the Soret effect may be a noteworthy process in some systems since chemical activity is highly dependent on temperature and the chemically driven heat flow- the Dufour effect requires investigation as little have been recorded in relation to geoenvironmental and geotechnical challenges. In this light, Darcy's law on its own may be an inadequate basis for prediction of hydraulic flow rates, mainly if the clayey material has high plasticity and very low void ratio as is the case with densely compacted barrier clay soils [6].

The determination of hydraulic conductivity is the major aim of conducting laboratory tests on samples of compacted natural treated or parent clayey soils. This determines the possibilities of the specimens being used as options in the construction of barrier lining systems. They serve as close replacement options for GMs at domestic and hazardous waste disposal and storage systems as well as, become environmental friendly and affordable construction components when properly handled. Such mechanical testing on soils judges whether a clayey soil barrier will hinder the percolation of heated leachates or leachates generally from reaching underlying water reserves thereby, posing consequential impacts [11]. A future test to be undertaken by the present authors, will sought to investigate the buffering capacity of some naturally occurring clayey soils sampled from a number of active South African landfills. This will help in the study of the leachate-soil interaction and may reveal possible implications on human health and the immediate environment as a whole. Based on the subject matter, literature recommends different specifications for index properties of soils i.e., Atterberg limits and particle-size distribution of the soils to serve as barrier lining material. The stated recommendations are generally meant for obtaining low-permeability values in the field after all necessary laboratory investigations are completed. It is for this reason that the US Environmental Protection Agency (EPA) stated that clay barriers should have hydraulic conductivity values in the order of 10^{-9}m/s or less. This is achievable by increasing soil workability and lowering/blocking pores and defects, which are potentially detrimental to the soil barrier by exposing it to wash offs of fine and thinning, and in severe cases, soil collapse. However, increasing the amount of fine-grained content, specifically in the clay/clayey material over the content of the coarse-grained material, reduces the value of the particle-crumb ratio allowed for the barrier lining material. Subsequently, on one hand, the exposure of the soil barrier macro-pores to potential risks and defects are reduced. While on the other hand, enhancing pore clogs/stiffness reduces the hydraulic conductivity of the soil barrier lining systems [6].

Factors/parameters as recorded by [12] fostering reduced hydraulic conductivity of compacted soil lining systems include but are not limited to the following: (i) optimum water content and the corresponding maximum dry unit weight of the compacted soil barrier (ii) size of the coarse and fine grains and (iii) soil structure and interlayer bonding. For simple mineral barriers i.e., bentonite liners, and in composite barrier systems (constituting a synthetic material), self-healing behaviours as known with bentonite materials are a very important contributing quality. This self-healing phenomenon entails the ability of the liner to close/seal up its fissures induced by external factors. Thus, retains the required effectiveness and efficiency of the barrier system over a long-term of its functional life span. This quality is recognized in conjunction with other soil properties to give considerable merit to natural treated or parent minerals as barrier liners. Hence, are considered reliable construction materials as they contribute to the repair of constructive deficiencies and potential crack lines and fissures in lining systems. With respect to intended laboratory investigations by the authors, locally available soil materials have been sampled from designated landfills around Johannesburg, South Africa for testing. During field reconnaissance, light expansive clay/clayey soils *e.g.,* kaolinitic, muscovitic and illitic soils were reported by landfill experts to be preferred over soil types with highly expansive tendencies *e.g.,* soils belonging to the smectite group with high swelling potentials. While samples with collapsible tendencies like marls or loess were rejected. In some tests documented by [6] using monovalent and bivalent salt solutions, the tested clay samples revealed better self-healing behaviours than expected. As was documented, illite was found to do better than kaolin, was less susceptible to desiccative effects and was only moderately expansive. Hydrous mica often known as illite is the most occurring clay soil mineral encountered in engineering practice [6]. This clay mineral type occurs as smallish, flaky particles mixed with other clay and non-clay compositions. Nonetheless, from the investigations by [6] single-mineral illite as reported by [13] does not occur as natural clay deposits in the quantity and the degree of purity needed for a case of landfill construction. A number of field studies have specifically shown that poor construction quality can negatively influence the permeability coefficients of compacted liner soils to several greater orders of magnitude as compared to laboratory measured values of the same soil [14]. For the reasons of varied laboratory to field value outcomes, US EPA established a requirement that laboratory test outcomes be confirmed in the field by using the same material and testing procedures that are to be initiated in real life scenarios [14].

Soil-Leachate Interaction/Compatibility Tests

In simple terms, "compatibility" in the present context refers to the potential impact of leachate contaminants (*e.g.,* heavy and light chemicals) on the characteristic properties of a material. The effect is triggered by the chemical interactions between the fluid (leachate) and the porous media (geo-composite material). A few relatively fast mechanical soil tests used in analyzing compatibility include; Atterberg limits, sedimentation (hydrometer test) and permeability. These are often used to hastily indicate compatibility problems [14]. While chemical tests as recorded by [7] to determine compound, elemental compositions and structural changes of the media is done using X-ray analysis prior and after contact with the chemical leachate solution. One of the most vital index property associated with cohesive soils is the plasticity index (PI). It is the difference between liquid limit (LL) and plastic limit (PL). The PI is related with soil volumetric changes and adds that the higher the PI of a soil, the higher its volume change characteristics, its plasticity and compressibility. Water content is the ratio between the weights of the water and the solids of the porous media. This value is established by weighing a portion of the soil both in its natural and dry states. The LL and PL are the water contents of a clay soil corresponding to the quasi-liquid state and the lower limit of the plastic behavior. The proposed PI–LL chart to different soil grains has been in use over a long period of time with the "A-line" separating clays and silts. If the LL and PI values of a fine-grained soil plot above the "A-line"-it is clay. However, if they plot below the "A-line"-the soil is silt. Where; "L" and "H" symbols as noted by [6] are used to describe a low or high plasticity fine-grained soil when LL is <50 or >50, respectively. Following the tests for Atterberg limits, leachate solutions are added to the selected samples in place of distilled water. From an experimental perspective, an increase in hydraulic conductivity can be considered significant if the final flow rate value reached surpasses the allowable maximum value.

In addition, soil-leachate compatibility/interaction is a very pertinent evaluation that should be done after the porous media has been slightly saturated by distilled water. The hydraulic conductivity of a media directly tested with some solution cannot be equal to the test value conducted with the same specimen exposed to water before the chemical leachate is introduced. For example, as described by [15] the behavior is different in terms of the expansion of a dense bentonite soil exposed initially to water compared with one followed by flocculation, when in contact with a highly concentrated electrolytic solution. However, since the clay barrier in the field is not likely to be saturated before exposure to chemical leachate, the significance of a dry and direct contact from an experimental glance may be appreciated. Looking at inorganic chemical substances, parameters of interest may include the following: concentration and solute type, pH and electrical conductivity of the solution, temperature and time of media-leachate exposure. The permeability of a porous media can be considerable affected when exposed to diluted inorganic compound as a result of their influence in flocculation and dispersion of particles in clayey soils [6].

Migration of Leachate-Salts to Consequential Levels

Impermeability measurements are majorly done to assess/determine the transportation of leachate contaminants through the layers of a porous media. Consequently, this largely depends on the water retention and contaminant buffering capacity of the of the soil medium. There are no fixed binding principles however for designing the evaluation approach of determining leachate migration through a porous system. For instance, as reported by [13] some German states use the cation exchange capacity (CEC) as the main characteristic parameter with which the buffering-migration interaction of a system is assessed. A minimum set value of 10 milliequivialent per 100g of soil (meq/100g) is used. There basically two modes of leachate contaminant travel through compacted clay barriers: (a) the advection mechanism- which relies on the hydraulic gradient, and (b) the diffusion mechanism- which is dependent on the concentration gradient. From recent discoveries, molecular diffusion has become the major cause for attention in the migration of leachate contaminants through fine-grained soils as against the traditional advective contaminant transport mechanism. However, in the retention of fluids, the traditional design of protective compacted clay barriers remains. Fine-grained soils having permeability values $< 1\times10^{-9}$m/s, may to a large extent buffer the diffusive migration of leachate contaminants. Advective and diffusive migration characteristics for systems with varying hydraulic conductivities have been recorded to fluctuate as follow: where, $k > 1\times10^{-8}$m/s implies that advection is dominant; where, $1\times10^{-10} < k < 1\times10^{-8}$m/s implies that both mechanisms are important, and if $k < 1\times10^{-10}$m/s then implies that diffusion is dominant [9]. The advection mechanism is based on Darcy's law ($q = ki$), while the diffusion mechanism is on Fick's law ($JD = DiC$), where i and iC = hydraulic and chemical gradients, respectively, q = volumetric flow rate per unit surface area, JD = chemical mass flux, expressed in units of moles per unit area per unit time, k = hydraulic conductivity with units of velocity, and D = fusion coefficient (cm^2/s), that is, the controlling parameter of the leachate contaminant migration [9].

Soils containing calcium carbonate and gypsum have fairly higher permeability values. The higher permeability relies on the electrolyte concentration and composition in the soil solution as well as, the clay mineral types and its exchangeable sodium percentage. As recorded in [9] alkali soils are characterized by the surface area distribution of fine grains that reduces the percolation of water through the soil system. Calcium carbonate ($CaCO_3$) or lime is a slightly soluble salt occurring in soils on pH scale above 7. The preferred adsorption of calcium and magnesium by soil particles results in a dislodgment of the adsorbed sodium. Other important source of calcium is the calcium sulfate-dihydrate (gypsum). Saline soils possess characteristic features of sufficient neutral soluble salts to reduce the bulging of soil colloids. Increased concentration of leachate electrolytes leads to an increased soil colloid flocculation and subsequently, increased permeability. Chloride or anions other than sulfate as observed by [16] must be present so that higher electrolyte concentrations in solution are possible. Increased solubility of minerals such as gypsum and calcite are dependent on an increased salt content (ionic strength) in the soil solution.

Heat Resistance/Insulation in Hot Leachate Ponds

A very vital property of mineral clay soil barrier utilized in heated ponds is its thermal conductivity among other characteristics. Geothermal loss (heat radiation) to the subsoil can substantially affect the efficiency and effectiveness of clay pond liners. In cases of minor thermal conductivity values, heat losses are reduced. Heat conductivity in soil systems occurs via the solid particles and also through water and air pores. The thermal conductivity of soil minerals as recorded by [18] is approximately 2.9W/m˚C, while those of water and air are 0.6 and 0.026W/m˚C respectively [9]. This is indicative that heat conductance occurs chiefly through the soil particles.

Due to insufficient documentations in this aspect of barrier lining soils, older studies by [17] were resorted to and recorded that kaolinite and bentonite had conductivity values < 0.6W/m˚C after the percolation of these compacted clay soil samples with hot NaCl (brines) for several months. Both illite (mica) and zeolites are regular constituents in locally available and naturally occurring soils. They are non-metallic and economically valuable minerals due to their natural-insulating properties. As such, they are more eco-friendly than synthetic materials and cost effective to a large extent- especially where they are naturally abundant. They have become highly considered in the design and construction of engineered disposal waste systems. As well constructed compacted clay lining barriers, they satisfy vast requirements of environmental management and waste disposal facility challenges with respect to the risk involved in energy reactors exposing the immediate environment to contamination via the travel of chemical species.

III. Conclusions

This paper drew attention to certain physical, chemical and hydraulic properties common to natural soils mainly for use as CCLs. It posited the functional and effective geoenvironmental design and construction of clay mineral barriers. Which when properly executed can be harnessed by underdeveloped nations as an essential component of a containment facility for heated and general leachate ponds as a sustained cost reducing option. In this light, the following conclusions were reached:

- Soil mineralogy and physicochemical properties provide qualitative means of assessing the probable trends of the tested materials. Chemical and heat-induced degradation processes could possibly alter the efficiency and effectiveness of clay soil barriers.
- Chemical analysis of leachate percolated soil samples together with compatibility studies can give information about the soil-leachate interactions and suggest relevant mechanisms like syneresis and thermo-diffusion via which clayey soil barrier may be affected.
- The wide variations in the properties of earthen materials used as heated pond liners can be characterized by their long-term performance in the presence of various contaminants.
- The sealing and heat insulation properties from earthen materials when properly executed can offer advantages which may particularly, favour their incorporation into rural development in underdeveloped countries.

Furthermore, it is pertinent to investigate the physicochemical aspects of clayey soils and related materials in order to overcome the potential disadvantages and make them more suitable as lining materials. However, as intended by the authors of this paper, investigations on leachate-soil interactions on samples collected form a number of active landfills will be carried out. The properties of the percolated sampled clay/clayey soils will be determined, as well as their attenuation capacity. This will indicate whether or not the soils require improvement, thus, make up a beneficial cost-effective approach on balancing the utilization of locally available earthen materials in preserving subsoil quality and in the long run improve the health state of the environment and its inhabitants.

Acknowledgment

The Authors appreciate the University of Johannesburg where the study was done.

References

[1] Jubran B.A., El-Baz A.R., Hamdan M.A. and Badran A.A. 1996. Experimental investigation of local clays and clay schemes as liners for solar ponds. International Journal of Energy Research 20, 637–642. http://dx.doi.org/10.1002/(SICI)1099-114X(199607)20:7<637::AID-ER178>3.0.CO;2-B

[2] Bouazza A., Zornberg J.G. and Adam D. 2002. "Geosynthetics in waste containment facilities", recent advances. Proceedings of 7th International Congress on Environmental Geotechnics, Delmas, Gourc and Girard (Eds.), pages: 445-507.

[3] Rowe R.K. 2011. "Systems engineering; the design and operation of municipal solid waste landfills to minimize contamination of groundwater". Geosynthetics International, September, 18 (6), pages: 319-404.

[4] Robbins M., Lu H. and Swift Jr. A. 1995. Investigation of the suitability of a geosynthetic clay liner system for the El Paso solar pond. In: Proceedings of the 1995 Annual Conference of American Solar Energy Society, USA, pp. 63–68.

[5] Daniel D.E. 1993. Geotechnical Practice For Waste Disposal. Chapman and Hall, London. http://dx.doi.org/10.1007/978-1-4615-3070-1

[6] Mitchell J.K. 1993. Fundamentals of Soil Behavior. Second ed. John Wiley and Sons, New York.

[7] Koerner R.M., Gartung E. and Zanzinger H. 1995. Geosynthetic clay liners. Proceedings of an International Symposium, (Eds.) A.A. Balkema, Rotterdam, Holland.

[8] Agbenyeku E.E. and Aneke I.F. 2014. Blended Rice Husk Ash Concrete; A Marginal Green Construction Material from Extended Hydration International Journal of Scientific and Engineering Research. Vol 5:1: pp. 906-910.

[9] Gerardo S. and Rafael A. 2009. Use of clays as liners in solar ponds. Solar Energy 83:905–919. http://dx.doi.org/10.1016/j.solener.2008.12.008

[10] Dewhurst D.N., Cartwright J.A. and Lonergan L. 1999. The development of polygonal fault systems by syneresis of colloidal sediments. Marine and Petroleum Geology 16, 793–810. http://dx.doi.org/10.1016/S0264-8172(99)00035-5

[11] Craig D.A. 1981. Organic leachate effects on the permeability of clay soils. M.Sc. thesis, Texas A&M University, USA.

[12] Auvinet G. and Esquivel R. 1986. Impermeabilizacio´n de Lagunas Artificiales. Limusa-SMMS, Mexico.

[13] August H., Holzlohner U. and Meggyes T. 1997. Advanced Landfill Liner Systems. Thomas Telford, (Eds.) London, Great Britain.

[14] Shackelford C.D. and de Mello L.G. 1994. Clay liner design, testing, and construction. In: Carrier, D. (Eds.), In: Proceedings of the 1st. International Congress on Environmental Geotechnics. Edmonton, Canada, pp. 984–987.

[15] Shackelford C.D. and Nelson J.D. 1996. Geoenvironmental design considerations for tailing dams. In: Proceedings of the International Symposium on Seismic and Environmental Aspects of Dams Design: Earth, concrete and tailings dams, vol. 1. Edmonton, pp. 131–186.

[16] Baver L.D., Gardner W.H. and Gardner W.R. 1972. Soils Physics, fourth ed. John Wiley and Sons, New York.

[17] Almanza R., Castaneda R. and Silva G. 1995. Temperature-electrolyte effects on clay soil liners. In: 1st International Conference on Unsaturated Soils, vol. 1. Paris, France, pp. 343–348.