UNIVERSITI PUTRA MALAYSIA

SUITABILITY OF USING COMPACTED GRANITE RESIDUAL SOIL TREATED WITH PALM OIL FUEL ASH AS HYDRAULIC BARRIER IN SANITARY LANDFILL

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By

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Thesis submitted to the School of Graduate Studies, Universiti Putra Malaysia, in fulfillment of the Requirements for the Degree of Master of Science

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DEDICATION

The project work is dedication to the Almighty Allah and my parents.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in Fulfilment of the requirement for the Degree of Master of Science

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Chair : Nik Norsyahariati Nik Daud, PhD

Faculty : Engineering

Modern landfills employ a composite liner system consisting of a geomembrane or geosynthetic clay liner overlying a compacted soil liner. For soils either natural or mixed with additive to satisfy the requirement of a liner, it must have low hydraulic conductivity, adequate shear strength and minimal shrinkage. An experimental investigation was conducted on granite residual soil treated with up to 15% palm oil fuel ash (POFA) to assess its suitability for liners in waste containment systems. Soil samples were prepared at moulding water content ranging from -2, 0, +2 and +4% of the optimum moisture content (OMC) and compacted with two compactive energy levels (standard and modified proctor). The tests carried out were divided into physical (moisture content, specific gravity, sieve analysis, Atterberg limit compaction), chemical (cation exchange capacitymineral composition, chemical oxides, structural morphology, elemental composition of leachate) and mechanical properties (hydraulic conductivity, volumetric shrinkage strain, unconfined compressive strength, compatibility studies) of both the natural soil and the mixture with POFA. Specific surface area was carried out on the POFA sample. The optimum properties of the soil mixture were then tested by carrying out the compatibility study. Compatibility study, which is the interaction between the leachate and the barrier material was determined based on the short – time hydraulic conductivity test using the leachate as the permeant. The concentrations of heavy metals contain in leachate before and after test were also assessed.

The results of the index properties of soil and soil – POFA mixture carried out provided a useful way to identify, classify and assess the engineering properties of the soil.The natural soil contained 53.13% fine content and that value increased to 59.14% with 15% POFA content. The index properties of samples met the minimum requirement for it to be used as a liner. Soils with high fine content have smaller particles that reduce the volume of voids present allow less hydraulic conductivity and also higher liquid limit are related to lower hydraulic conductivity. Chemical composition of POFA showed a fair result of 67.80% in comparison to the minimum requirement of 70% for pozzolanic reaction as stated by ASTM. While on the other

hand, the addition of POFA showed a modification in the structure of the soil from a porous to a dense structure.

The maximum dry density and optimum moisture content decreased and increased respectively for both compactive efforts. For both compactive energies, the hydraulic conductivity generally decreased with increase in moulding water content, the lowest were obtained at the wet side of the compaction curve especially at +2% of the optimum moisture content. At modified proctor compactive effort and +2% of the OMC, hydraulic conductivity values of 6.51×10^{-9}, 2.23×10^{-10}, 2.31×10^{-11} and 1.31×10^{-9}m/s were obtained at 0, 5, 10 and 15% POFA, respectively. However, beyond +2% of the OMC, there was a slight increase in hydraulic conductivity values. For the volumetric shrinkage strain (VSS), there was increase in VSS values with higher moulding water content and also at higher initial degree of saturation for all compactive efforts. The largest VSS value of 5.91% was obtained at soil containing 15% POFA and +4% of the OMC. The influence of POFA treatment generally showed a decrease in the VSS with the increase in POFA content. On the other hand, shear strength values increased with the addition of POFA and at higher compactive effort, with the highest strength recorded at 10% POFA using modified proctor compactive effort. However, the values decreased at higher moulding water content irrespective of POFA content and compactive effort. Based on the acceptable zone on the compaction plane, 10% POFA gave the widest range ofmoulding water content in which minimumset of values based on the hydraulic conductivity, shear strength and volumetric shrinkage were achieved.

For a compatibility study, results showed that there was a general decrease in hydraulic conductivity values at different percentages of POFA, with the highest reduction rate of 65.4% recorded at 10% POFA mixture. This could be as a result of suspended solids in the leachatewhich were absorbed at the surface of the soil there by reducing percolation with time. On the other hand the concentration of some metals was drastically reduced when permeated through the compacted material.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk Ijazah Master Sains

KESESUAIAN MENGGUNAKAN TANAH BAKI GRANITTERPADAT YANG DIRAWAT DENGAN ABU BAHAN API KELAPA SAWIT SEBAGAI PENGHALANG HIDRAULIK DI TAPAK PELUPUSAN SANITARI

Oleh

ABUBAKAR SADIQ MUHAMMED

Februari 2015

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Fakulti : Kejuruteraan

Tapak pelupusan sampah moden menggunakan sistem pelapik komposit yang terdiri daripada pelapik geomembran atau pelapik tanah liat geosintetik yang dilapis diatas pelapik tanah termampat. Pelapik tanah, sama ada tanah semula jadi atau tanah yang dicampur bahan tambahan mestilah mempunyai kekonduksian hidraulik yang rendah, kekuatan ricih yang mencukupi dan pengecutan yang minimum. Satu eksperimen telah dijalankan terhadap tanah sisa granit yang dirawat dengan abu bahan api kelapa sawit (POFA) untuk menilai kesesuaiannya sebagai pelapik dalam sistem pelupusan sampah. Sampel tanah disediakan dalam kandungan lembapan optimum (OMC) antara -2,0, +2 dan +4% dan kemudian dimampatkan dengan dua tahap tenaga pemadatan (proktor standard dan proktor diubahsuai). Ujian-uiian terhadap kedua-dua jenis tanah semula jadi dan tanah campuran POFA termasuk ujian fizikal (kandungan lembapan, graviti tentu, analisis ayakan, had Atterberg, pemadatan), kimia (komposisi mineral, oksida kimia, morfologi struktur, komposisi unsur larutan resapan, kapasiti pertukaran kation) dan sifat-sifat mekanik (kekonduksian hidraulik, terikan pengecutan isipadu, kekuatan mampatan tak terkurung, kajian kesesuaian). Luas kawasan permukaan tertentu bagi POFA juga dikenalpasti. Kemudian ciri-ciri optimum tanah campuran tersebut digunakan untuk menguji kesesuaiannya. Kajian kesesuaian, iaitu merupakan interaksi antara bahan larut resap dan bahan penghadang telah diuji berdasarkan ujian kekonduksian hidraulik jangka pendek. Kepekatan logam berat didalam air larut resap dinilai sebelum dan selepas kajian kesesuaian dilakukan.

Berdasarkan keputusan dari kajian yang dilakukan, ciri indeks tanah semulajadi dan tanah campuran POFA adalah berguna untuk mengenal pasti, mengklasifikasi dan menilai sifat-sifat kejuruteraan tanah tersebut. Tanah semula jadi mengandungi kandungan halus 53.13% dan nilai tersebut meningkat kepada 59.14% dengan 15% kandungan POFA.Sifat indeks sampel adalah menepati keperluan minimum untuk digunakan sebagai bahan pelapik. Tanah dengan kandungan halus yang tinggi mempunyai zarah lebih kecil yang mengurangkan isipadu lompang dalam tanah. Ini menyebabkan kekonduksian hidraulik berkurang dan juga had cecair yang tinggi

berkaitan dengan kekonduksian hidraulik yang rendah.Komposisi kimia POFA menunjukkan hasil sebanyak 67.80% jika dibandingkan dengan keperluan minimum sebanyak 70% untuk tindak balas pozzolonik seperti yang dinyatakan dalam ASTM. Dari sudut lain, campuran POFA menunjukkan pengubahsuaian di dalam struktur tanah dari poros kepada padat.

Ketumpatan kering maksimum menurun manakala kandungan lembapan optimum meningkat untuk kedua-dua jenis pemadatan. Untuk kedua-dua jenis pemadatan, secara amnya kekonduksian hidraulik menurun dengan peningkatan pembentukan kandungan air, dengan nilai terendah didapati pada bahagian lembap pada lengkung pemadatan terutama pada kandungan lembapan optimum sebanyak +2%. Bagiusaha pemadatan proctor diubahsuai dan +2% OMC, nilai kekonduksian hidraulik 6.51×10^{-9}, 2.23×10^{-10}, 2.31×10^{-11} dan 1.31×10^{-9}m/s diperolehi pada 0, 5, 10 dan 15% POFA. Walaubagaimanapun, apabila OMC melebihi +2%, terdapat sedikit peningkatan pada nilai kekonduksian hidraulik. Bagi pengecutan isipadu terikan (VSS),terdapat peningkatan bagi nilai VSS dengan kadar pembentukan kandungan air yang lebih tinggi, begitu juga pada darjah ketepuan awal yang lebih tinggi bagi kedua-dua jenis pemadatan. Nilai VSS terbesar 5.91% telah diperolehi pada tanah yang mengandungi 15% POFA dan +4% daripada OMC. Secara amnya, nilai VSS menurun dengan peningkatan kandunganPOFA. Sebaliknya dengan penambahan POFA, nilai kekuatan ricih meningkat dengan penambahan POFA pada pemadatan yang lebih tinggi dengan kekuatan paling tinggi direkod pada 10% POFA dengan menggunakan usaha pemadatan proctor diubahsuai.Walaubagaimanapun, nilai kekuatan ricih menurun apabila pembentukan kandungan air tinggi tanpa mengira kandungan POFA usaha pemadatan. Berdasarkan zon boleh terima pada satah pemadatan, kandungan POFA sebanyak 10% memberikan julat kandungan air yang lebih luas, di mana set nilai minimum berdasarkan kekonduksian hidraulik, kekuatan ricih dan pengecutan isipadu telah dicapai.

Untuk kajian kesesuaian, keputusan menunjukkan bahawa secara amnya terdapat penurunan dalam nilai kekonduksian hidraulik mengikut peratusan POFA yang berbeza, dengan kadar pengurangan tertinggisebanyak 65.4% direkodkan pada campuran 10% POFA.Ini mungkin disebabkan oleh pepejal terampai yang tersapat di dalam air larut resap yang mana telah melekat pada permukaan tanah maka mengurangkan penelusan mengikut masa. Sebaliknya, kepekatan beberapa jenis logam telah menurun dengan drastik apabila air larut resap melalui bahan terpadat.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science.

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LIST OF ABBREVIATIONS

ASTM	American Society for Testing and Materials
BOD	Biochemical Oxygen Demand (mg/l)
CEC	Cation Exchange Capacity (mg/l)
COD	Chemical oxygen demand (mg/l)
CL	Low Plasticity Clay
ICDD	International Centre for Diffraction Data
LL	Liquid Limit (%)
LS	Linear shrinkage (%)
MDD	Maximum Dry Density (Mg/m^3)
MP	Modified Proctor
MSW	Municipal Solid Waste
OMC	Optimum Moisture Content (%)
PI	Plasticity index (%)
PL	Plastic Limit (%)
POFA	Palm Oil Fuel Ash
SEM	Scanning Electron Microscope
SP	Standard Proctor
TSS	Total suspended solids (mg/l)
UCS	Unconfined compressive Strength (kNm^2)
USCS	Unified Soil Classification System
VSS	Volumetric Shrinkage Strain (%)
XRD	X- Ray Diffraction
XRF	X-Ray fluorescence
ZAV	Zero Air Void (Mg/m^3)

CHAPTER 1

INTRODUCTION

An industrious society is a waste-generating society. Nowadays, there is a radical increase in the quantity of waste generated throughout the world. This could be due to the degree of industrialization, rapid population growth, urbanization and use of modern technology in our daily lives. These wastes are harmful to mankind; therefore, there is a need for careful disposal practice. Generally, the practice of waste disposal has been carried out with little regards to the environment, such as open dumping and dumping along river banks (Cawley and Jones, 1999). Unfortunately, in developing countries, the practice continues without concern with its impacts to the environment.

The current global Municipal Solid Waste (MSW) generation levels are approximately 1.3 billion tonnes per year and are expected to increase to approximately 2.2 billion tonnes per year by 2025. This represents a significant increase in the per capita of waste generation rates; that is, from 1.2 to 1.42 kg per person per day in the next fifteen years (Hoornweg and Bhada, 2012). According to the same source, the current Municipal Solid Waste generated in Malaysia specifically is 21,918 tonnes/day, and the amount is expected to rise to 51,656 tonnes/ day in 2025. Going by this information, stakeholders in the environmental sector are saddled with the responsibility to provide a more economic, safe and efficient waste disposal method. The major options for dealing with wastes include incineration and landfilling practices. In the near future, landfilling will continue to be the best option because incineration is not a viable method for wide variety of wastes such as mill waste and other incombustibles. Furthermore, incineration may lead to air pollution problems and will leave ash residue that will still require disposal in a landfill (Qian et al., 2002; Ahsan et al., 2014). Therefore, it is significant to give maximum concern on landfill, which will go a long way to minimise environmental problems. However, one of the major problems associated with landfilling is the high amount of leachate generated, which can be a source of pollution to the ground water body due to the heavy pollutants contained in it (Kjeldsen et al., 2002; Chen and Zhan, 2010; Raghab et al., 2013). In order to reduce the problem associated with leachate, a good lining system must be put in place which does not only perform the act of isolating waste from contaminating the soil, but also prevents the integrity of the ground water system by preventing or rather reducing percolation of leachate (Koivula et al., 2009).

Compacted natural soils are widely used as hydraulic barrier in waste–containment system. However, in recent years it has become difficult to find locally available soils that meet the requirement to be used as liners. The most common type of liner or hydraulic barrier as mentioned by Cawley (1999) is compacted clay liner, and it has proven to be effective in the containment system of municipal solid waste (MSW). The main aim of a hydraulic barrier is to minimize or prevent the percolation of leachate into the ground water body; hence, the most vital property that affects its performance is the hydraulic conductivity. The hydraulic conductivity of compacted clay soils is sequentially influenced by the Atterberg limits, particle size distribution and compaction variables. Daniel and Benson (1990) stated that compacted clay liner should have a maximum hydraulic conductivity of 1×10^{-7} cm/s. The stated maximum hydraulic conductivity also conforms to the one stated by the American Environmental Protection Agency (EPA, 1989). Other criteria to be considered in the design and construction compacted clay liner are shear strength, volumetric strain of the compacted soil, water content and compactive effort to achieve minimum hydraulic conductivity, and of course, chemical compatibility of the liner (EPA, 1989; Daniel and Benson, 1990; Eberemu, 2013; Osinubi et al., 2006). Figure 1.1 shows a typical section of a landfill with compacted clay as a last layer beneath the earth, it serves as a backup for the plastic liner.

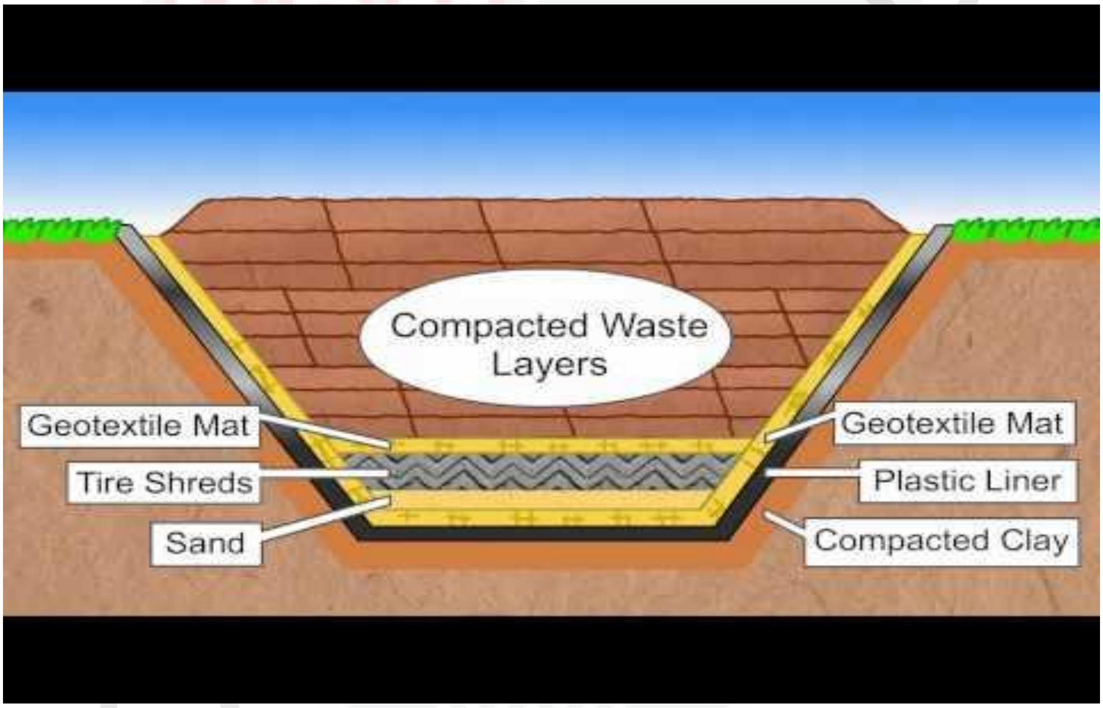

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Figure 1.1: Typical section of a landfill

The annual global agricultural waste generation rate is about 998 million tonnes, and in Malaysia, 1.2 million tonnes of agricultural waste are disposed into landfill (Tahir and Hamid, 2012). One of the main crops being cultivated in Malaysia is the oil palm. As of 2011, palm oil cultivation in Malaysia occupies about five million hectares of land, making it the crop with the largest landmass for production (http://mpob.gov.my/). Therefore, a high production of palm oil fuel ash (POFA) which is a considered to be a waste from the milling operation, is on the high side. However, a considerable amount of literature has been published on the utilization of POFA as a partial replacement of cement (Altwair et al., 2014; Bamaga, et al., 2013; Tangchirapat et al., 2009).

Previous research has examined the effect of different types of agricultural and industrial waste mixed with various types of soils to be used as hydraulic barrier in landfill (Eberemu et al., 2013; Moses and Afolayan, 2011; Osinubi and Amadi, 2009). However, their studies emphasized more on the mechanical properties of these materials. This study is going to further carried out compatibility tests between the soil – POFA mixture and the leachate, aimed at determining the hydraulic conductivity of the material after prolong contact with the leachate. Additionally, it went on to check the concentration of some heavy metals before and after the permeation in order to ascertain the percentage reduction in the concentration of the some heavy metals.

1.1 Problem Statement

The concept of open dumping of waste in most transition countries results in adverse health and environmental hazards due to migration of cations such as lead, chromium, manganese and other contaminants through water. Landfilling is the most common method of solid waste disposal practice used by many communities for many years (Kholmatov et al., 2010; Komiliset al., 1999; Ahsan et al., 2014). It is the most important method of waste management because all other methods produce residue that cannot be used further and are lastly, landfilled.

The major problem associated with landfills is leachate; it occurs as a result of moisture acting as a solvent seeping through the landfill cover. It constitutes of organic and inorganic ions that are found in wastes. The release of leachate to the groundwater may cause several risks to human health and the environment by rendering the aquifer unsuitable for drinking and other uses.

Some of the common materials used as hydraulic barrier include geosynthetic liners, composite liners, natural clayey soils, which may be processed clay or sand-processed clay mixture (Rahman et al., 2013; Bowders et al., 1987; Cawley and Jones, 1999; Abichou et al., 2000; Albrecht and Benson, 2001; Singh and Prasad, 2007). Large quantity of waste generated from agricultural and industrial sources has prompted researchers to look for alternative approaches for the design of hydraulic barrier systems. With the advent of sustainable development, research into new waste materials is on the forefront in order to ensure reuse of waste, which could be agricultural waste or industrial waste. Examples of such waste materials are bagasse ash, rise husk ash, groundnut shell ash, palm oil fuel ash, blast furnace slag, cement kiln dust and fly ash. These approaches include mixing these waste materials with local available soil to produce a suitable blended material.

1.2 Aims and Objectives

The aim of the research is to determine the suitability of using compacted granite residual soil mixed with palm oil fuel ash (POFA) to be used as hydraulic barrier in sanitary landfills.

The specific objectives area to determine:

i. the effect of different percentages of palm oil fuel ash (POFA) on the hydraulic conductivity, shear strength and volumetric shrinkage strain of granite residual soil;
ii. the relationship of the above properties with increase in compactive effort and moulding water content;
iii. the overall acceptable zone of soil – POFA mixture as hydraulic barrier based on the properties mentioned above and
iv. the chemical compatibility and attenuative capacity of granite residual soil - POFA mixture with landfill leachate.

1.3 Scope and Limitations

The research focuses on suitability studies of granite residual soil – palm oil fuel ash (POFA) mixture as material for hydraulic barrier for municipal solid waste landfill. Specific mechanical properties such as hydraulic conductivity, shear strength and the effect of environmental factors such as desiccation of the compacted liner were studied. The compatibility of the proposed liner material and municipal solid water leachate were also studied. The design of the liner thickness based on the environmental factors as well as the type of leachate was beyond the scope of this work. This study concentrated only on municipal solid waste (MSW); it will not take into cognizance of industrial solid waste.

1.4 Justification

Modern landfills employ a composite liner system consisting of a geomembrane or geosynthetic clay liner overlying a compacted clay liner. This is because geosynthetic clay liners and geomembrane when used alone, suffer from high diffusion flux and as such, do little to inhibit the transport of leachate, which diffuses readily through geomembrane polymers (Edil 2003; Rowe et. al., 2004). Furthermore, a number of household chemicals such as margarine, oil and shoe polish commonly found in municipal solid waste (MSW), degrade the geomembrane and geosynthetic, making it soft, brittle and susceptible to cracking and eventual loss of strength. Compacted clay liners component usually provide a diffusion barrier that controls the rate of transport of the volatile organic compound.

The assumption is that success will be recorded in partly replacing the costly composite system with readily, and economically available granite residual soil – POFA mixtures that will provide a back-up for synthetic barriers; hence, a cost effective means of getting the required environmental protection.

1.5 Thesis Organization

This thesis consists of five chapters, which are the introduction, literature review, materials and methods, results and discussion and finally the conclusions and recommendations. Chapter one is an introductory chapter presenting the problem statement, research objectives, justification and the scope the study. Chapter Two provides a literature review on the major parameters used to evaluate the performance of a hydraulic barrier material. The effects of various agricultural wastes, moulding water content and compactive efforts on the mechanical properties of different types of soil were discussed. Chapter Three presents a description of the experimental methods, materials and techniques as well as testing procedures employed in this research. Results, discussions and inferences based on extensive experimental data obtained are presented in Chapter Four. Finally, the presentation of conclusive statements and some suggestions for further studies are discussed in Chapter Five.

REFERENCES

Abdi, M. R., Parsapajouh, A., &Arjomand, M. A. (2008). Effects of random fiber inclusion on consolidation, hydraulic conductivity, swelling, shrinkage limit and desiccation cracking of clays. *International Journal of Civil Engineering*, *6*(4), 284–292.

Abdullah, K., Hussin, M. W., Zakaria, F., Muhamad, R., & Abdul Hamid, Z. (2006). POFA: A potential partial cement replacement material in aerated concrete. Retrieved from
http://eprints.utm.my/377/

Abichou, T., Benson, C. H., & Edil, T. B. (2000). Foundry green sands as hydraulic barriers: laboratory study. *Journal of Geotechnical and Geoenvironmental Engineering*, *126*(12), 1174–1183.

Abichou, T., Benson, C. H., & Edil, T. B. (2002). Foundry green sands as hydraulic barrier: Field study. *Journal of Geotechnical and Geological Engineering*, 121(6), 493-502.

Abu-Hejleh, A. N., & Znidarcic, D. (1995). Desiccation theory for soft cohesive soils. *Journal of Geotechnical Engineering*, *121*(6), 493–502.

Acar, Y. B., & Olivieri, I. (1989). Pore fluid effects on the fabric and hydraulic conductivity of laboratory – compacted clay. Transportation Research Records, (1219), 144 -159

Ahmad, F., Yahay, A. S., &Farooqi, M. A. (2006). Characterization and geotechnical properties of Penang residual soils with emphasis on landslides. *American Journal of Environmental Sciences*, *2*(4), 121.

Ahn, H.-S., & Jo, H. Y. (2009). Influence of exchangeable cations on hydraulic conductivity of compacted bentonite. *Applied Clay Science*, *44*(1), 144–150.

Ahsan, A. M. Alamgir, M. M. El-Sergany, S. Shams, M. K. Rowshon, and N. N. Nik Daud, "Assessment of municipal solid waste management system in a developing country," *Chinese Journal of Engineering*, vol. 2014, Article ID 561935, 11 pages, 2014.

Akoto, B. K. A., & Singh, G. (1981). Some geotechnical properties of a lime-stabilized laterite containing a high proportion of aluminium oxide. *Engineering Geology*, *17*(3), 185 - 199.

Albrecht, B. A., & Benson, C. H. (2001). Effect of desiccation on compacted natural clays. *Journal of Geotechnical and Geoenvironmental Engineering*, *127*(1), 67–75.

Alhassan, M.,Mesaiyete, E., & Mustapha, A. M. (2012). Clay mineralogy of lateritic soils derived from granite basement – acase study of Minna lateritic soils. *Journal of Geotechnical Engineering*, *17*, 1897–1903.

Alhassan, M., Mustapha, A. M., & Mesaiyete, E. (2014). Influenceof clay mineralogy onplasticity of lateritic soils, *11*(3), 18–21.

Altwair, N. M., Johari, M. A. M., & Hashim, S. F. S. (2011). Strength activity index and microstructural characteristics of treated palm oil fuel ash. *International Journal of Civil & Environmental Engineering, 11(5), 100 – 107.*

Altwair, N. M., Johari, M. M., & Hashim, S. F. S. (2014). Influence of treated palm oil fuel ash on compressive properties and chlorideresistance of engineered cementitious composites. *Materials and Structures*, *47*(4), 667–682.

Amadi, A. A. (2011). Hydraulic conductivity tests for evaluating compatibility of lateritic soil—fly ash mixtures with municipal wasteleachate. *Geotechnical and Geological Engineering*, *29*(3), 259–265.

Amadi, A. A., & Eberemu, A. O. (2012). Delineation of compaction criteria for acceptable hydraulic conductivity of lateritic soil-bentonite mixtures designed as landfill liners. *Environmental Earth Sciences*, *67*(4), 999–1006.

Amadi, A. A., & Eberemu, A. O. (2012). Performance Of Cement Kiln Dust In Stabilizing Lateritic Soil Contaminated with Organic Chemicals. *Advanced Materials Research*, *367*, 41–47.

Amadi, A. A., & Eberemu, A. O. (2013). Potential application of lateritic soil stabilized with cement kiln dust (CKD) as liner in waste containment structures. *Geotechnical and Geological Engineering*, 31(4) 1221-1230.

Amadi, A. A., Eberemu, A. O., & Osinubi, K. J. (2012). Strength consideration in the use of lateritic soil stabilized with fly ash as liners and covers in waste landfills. *State-of-the-Art and Practice in Geotechnical Engineering, Geotechnical Special Publication (GSP) ASCE*, (225), 3835–3844

Amadi, A. A., & Osinubi, K. J. (2010). Assessment of bentonite influence on hydraulic conductivity of lateritic soil. *International Journal of Engineering Research in Africa*, 3, 84 – 93.

Amzar, Y., & Suwandi, A. K. (2006). The suitability of POFA (palm oil fuel ash treated clay soil for liner material in sanitary landfill. Universiti Tun Hussein Onn, Malaysia.Retrieved from http://eprints.uthm.edu.my/1947/

APHA (2005). Standard methods for the examination of water and wastewater. *21 ed.* Washington D.C: American Public Health Association.

Asavapisit, S., Tanapaibonkul, N., Jenwittayawetchakum, P., & Sungworpatansakul, W. (2003). Effects of mineral additives on strength and hydraulic properties of compacted clayey soil. *WarasanTechnology Suranari*, 10. Retrieved from: http://agris.fao.org/agris-

ASTM Standard C618-08a: Standard specification for coal fly ash and raw or calcined natural pozzolan for use in concrete, *Annual Book of ASTM Standards*, ASTM International, West Conshohocken, PA, 2008.

Aziz, H. A., Daud, Z., Adlan, M. N., & Hung, Y. T. (2009). The use of poly aluminium chloride for removing colour, COD and ammonia from semi-aerobic leachate. *International Journal of Environmental Engineering*, *1*(1), 20–35.

Bamaga, S. O., Hussin, M. W., & Ismail, M. A. (2013). Palm Oil Fuel Ash: Promising supplementary cementing materials. *KSCE Journal of Civil Engineering*, *17*(7), 1708–1713.

Bamaga, S. O., Ismail, M. A., & Hussin, M. W. (2011). Chloride resistance of concrete containing palm oil fuel ash. *Concrete Research Letters*, *1*(4), 158–166.

Bello, A. A., & Osinubi, K. J. (2011). Attenuative Capacity of Compacted abandoned dumpsite soil. *Electronic Journal of Geotechnical Engineering*, (16) 71 – 91.

Benson, C. H., & Daniel, D. E. (1990). Influence of clods on the hydraulic conductivity of compacted clay. Journal of Geotechnical Engineering, 116(8), 1231 – 1248.

Benson, C. H., Daniel, D. E., & Boutwell, G. P. (1999). Field performance of compacted clay liners. *Journal of Geotechnical and Geoenvironmental Engineering*, *125*(5), 390–403.

Benson, C. H., & Khire, M. V. (1995). Earthen covers for semi-arid and arid climates. In *Landfill Closures, Environmental Protection and LandRecovery* (pp. 201–217).Retrieved from http://cedb.asce.org/cgi/WWWdisplay.cgi?9505550

Benson, C. H., & Trast, J. M. (1995). Hydraulic conductivity of thirteen compacted clays. *Clays and Clay Minerals*, *43*(6), 669–681.

Benson, C. H., Zhai, H., & Wang, X. (1994). Estimating hydraulic conductivity of compacted clay liners. *Journal of Geotechnical Engineering*, *120*(2), 366–387.

Bergman, E. F. &McKnight, T. L. (1993). Introduction to geography. Englewood Cliffs, New Jersey Prentice Hall.

Bowders, J. J., Usmen, M. A., & Gidley, J. S. (1987). Stabilized fly ash for use as low – permeability barriers. In Geotechnical Practice for Waste Disposal (pp. 320 – 333) ASCE.

Boynton, S. S., & Daniel, D. E. (1985). Hydraulic conductivity tests on compacted clay. *Journal of Geotechnical Engineering*, *111*(4), 465–478.

Bronswijk, J. J. B. (1988). Modelling of water balance, cracking and subsidence of clay soils.*Journal of Hydrology*, *97*(3), 199–212.

Brown, K. W., & Anderson, D. (1980). Effect of Organic Chemicals on Clay Liner Permeability; A Review of the Literature. *Available from the National Technical Information Service, Springfield VA 22161 as PB 80-175086, Price Codes: A 13 in Paper Copy, A 01 in Microfiche. In: Disposal of Hazardous Waste*.

Brown, O. R., Yusof, M. B. B. M., Salim, M. R. B., & Ahmed, K. (2011a). Compaction parameters of kaolin clay modified with palm oil fuel ash as landfill liner. In *Clean Energy and Technology (CET), 2011 IEEE First Conference onclean Energy and Technology*(pp. 199–204).

Brown, O. R., Yusof, M., Salim, M. R. B., & Ahmed, K. (2011b). Physico-chemical propertiesof palm oil fuel ash as composite sorbent in kaolin clay landfill liner system. In*Clean Energy and Technology (CET), 2011 IEEE First Conference onclean Energy and Technology* (pp. 269–274).

BS1377, (1990). 2: 1990. British standard methods of test for soils for civil engineering purposes, Part 2: Classification test. *British Standards Institution, London.*

BS 5930: (1999). Code of practice for site investigations, *British Standards Institution, London*

Cawley, M. R.,& Jones, N. (1999). Compacted clay liners. Retrieved from http://ce540.groups.et.byu.net/syllabus/termpaper/1999-W/cawley.pdf

Cawley, M.R. (1999). Compacted clay liners – A viable solution for landfill leachate containment. Winter Semester 1999, Brigham Young University.

Chang, R. K., & Warkentin, B. P. (1968). Volume change of compacted clay soil aggregates. *Soil Science*, *105*(2), 106–111.

Chaosheng, T. (2011). Shrinkage and cracking behaviour of swelling soil under different temperatures. Retrieved from http://www.paper.edu.cn/en_releasepaper/downPaper/201101-673

Chapman, H.D. 1965. Cation-exchange capacity. *In:* C.A. Black (ed.). Methods of soil analysis - Chemical and microbiological properties. Agronomy 9:891-901

Chen, Y. M., & Zhan, T. L. (2010). Environmental geotechnics related to landfills of municipal solid wastes. In *Advances in Environmental Geotechnics* (pp. 132–152). Springer

Cokca, E., & Yilmaz, Z. (2004). Use of rubber and bentonite added fly ash as a liner material. *Waste Management*, *24*(2), 153–164.

Daniel, D. E. (1984). Predicting hydraulic conductivity of clay liners. *Journal of Geotechnical Engineering*, *110*(2), 285–300.

Daniel, D. E. (1987). Earthen liners for land disposal facilities. In *Geotechnical* practice for waste disposal (pp. 21-39). Retrieved from http://cedb.asce.org/cgi/WWWdisplay.cgi?52506

Daniel, D. E., & Benson, C. H. (1990). Water content-density criteria for compacted soil liners. *Journal of Geotechnical Engineering*, *116*(12), 1811–1830.

Daniel, D. E., & Koerner, R. M. (1993). *Quality assurance and quality control for waste containment facilities*. Risk Reduction Engineering Laboratory, Office of Research and Development, US Environmental Protection Agency. Retrieved from http://nepis.epa.gov/Adobe/PDF/30002ZO7.pdf

Daniel, D. E., & Wu, Y.K. (1993). Compacted clay liners and covers for arid sites. *Journal of Geotechnical Engineering, 119*(2), 223–237.

D'Appolonia, D. J. (1980). Soil – bentonite slurry trench cutoffs. *Journal of Geotechnical Engineering Division,* 106(4), 399 – 417.

Eberemu, A. O. (2011). Desiccation induced shrinkage of compacted tropical clay treated with rice husk ash. *International Journal of Engineering Research in Africa*, *6*, 45–64.

Eberemu, A. O. (2013). Evaluation of bagasse ash treated lateritic soil as a potential barrier material in waste containment application. *Acta Geotechnica,* 1–15.

Eberemu, A. O., Amadi, A. A., & Osinubi, K. J. (2012). The Use of Compacted Tropical clay treated with rice husk ash as a suitable hydraulic barrier material in waste containment application. *Waste and Biomass Valorisation*, 1 – 15.

Eberemu, A. O., Amadi, A. A., & Osinubi, K. J. (2013). The use of compacted tropical clay treated with rice husk ash as a suitable hydraulic barrier material in waste containment applications. *Waste and Biomass Valorization*, 1–15.

Eberemu, A. O., Amadi, A. A., & Sule, J. (2011). Desiccation effect on compacted tropical clay treated with rice husk ash. In *Geo-Frontiers 2011@ Advances in Geotechnical Engineering* (pp. 1192-1201). ASCE.

Edil, T. B. (2003). A review of aqueous-phase VOC transport in modern landfill liners.*Waste Management*, *23*(7), 561–571.

Edil, T. B., Sandstrom, L. K., &Berthouex, P. M. (1992). Interaction of inorganic leachate with compacted pozzolanic fly ash. *Journal of Geotechnical Engineering*, *118*(9), 1410–1430.

EPA (1989). Requirements for hazardous waste landfill design, construction and closure Environmental Protection Agency Publ. No. EPA-625/4-89-022, Cincinnati Ohio.

Foo, K. Y., & Hameed, B. H. (2009). Value-added utilization of oil palm ash: A superior recycling of the industrial agricultural waste. *Journal of Hazardous Materials*, *172*(2),523-531.

Francisca, F. M., & Glatstein, D. A. (2010). Long term hydraulic conductivity of compacted soils permeated with landfill leachate. *Applied Clay Science*, *49*(3), 187–193.

Frempong, E. M., & Yanful, E. K. (2008). Interactions between three tropical soils and municipal solid waste landfill leachate. *Journal of Geotechnical and Geoenvironmental Engineering*, *134*(3), 379–396.

Frempong, E. M., & Yanful, E. K. (2008). Interactions between three tropical soils and municipal solid waste landfill leachate. *Journal of Geotechnical and Geoenvironmental Engineering*, *134*(3), 379–396.

Fronczyk, J., & Garbulewski, K. (2013). Hydraulic conductivity of zeolite-sand mixtures permeated with landfill leachate. Retrieved from http://www.geotech-r.org/sites/default/files/congres/cimsg/3021.pdf.7

George, M. (2012). *Hydraulic and contaminant transport performance of compacted bagasse ash treated foundry sand for use in waste containment facilities*. (Doctoral dissertation Department of Civil Engineering, Faculty of Engineering, Ahmadu Bello University).Retrieved from: http://196.220.64.8:8080/jspui/handle/123456789/3376

Glatstein, D. A., & Francisca, F. M. (2014). Hydraulic conductivity of compacted soils controlled by microbial activity. *Environmental Technology*, *35*(15), 1886–1892.

Goldman, L. J., Greenfield, L. I., Damle, A. S., Kingbury, G. L., Northeim, C. M., & Truesale, R. S. (1990). *Clay liners for waste management facilities: design, construction and evaluation*. Noyes Data. Retrieved from http://bases.bireme.br/cgin/wxislind.exe/iah/online/?IsisScript=iah/iah.xis&src=google&base=REPIDISCA&lang=p&nextAction=lnk&exprSearch=81827&indexSearch=I

Gordon, M. E., Huebner, P. M., &Miazga, T. J. (1989). Hydraulic conductivity of three landfill clay liners. *Journal of Geotechnical Engineering*, *115*(8), 1148 – 1160.

Gray, D. H. (1989). Geotechnical engineering of land disposal systems. In *The Landfill* (pp. 145–173). Springer. Retrieved from http://link.springer.com/chapter/10.1007/BFb0011263

Guney, Y., Cetin, B., Aydilek, A. H., Tanyu, B. F., &Koparal, S. (2014). Utilization of sepiolite materials as a bottom liner material in solid waste landfills. *Waste management*, *34*(1), 112-124.

Guney, Y., Koparal, S., &Aydilek, A. H. (2008). Sepiolite as an alternative liner material inmunicipal solid waste landfills. *Journal of Geotechnical and Geoenvironmental Engineering*, *134*(8), 1166–1180.

Palm Oil Facts & Figures

Haines, W. B. (1923). The volume changes associated with variations of water content in soil. *J. Agric. Sci*, *13*, 296–310.

Head, K. H. (1992). Manual of soil laboratory testing. *Soil classification and compaction tests*, 2nd Ed., Vol. 1, Pentech Press, London

Holtz, R. D., & Kovacs, W. D. (1981). *An introduction to geotechnical engineering*. Retrievedfrom http://trid.trb.org/view.aspx?id=214980

Hoornweg, D., & Bhada, P. (2012). What a waste: a global review of solid waste management. No. 15. www.worldbank.org/urban.

Huat, B. B., Gue, S. S., & Ali, F. H. (2004). *Tropical residual soils engineering*. Taylor & Francis. Retrieved from http://books.google.com.my/books?hl=en&lr=&id=tifxwI2nbcQC&oi=fnd&pg=PP1&dq=tropical+residual+soil+engineering+&ots=q7iA23iX_T&sig=EPBr0T_LAR8YvHiP4VwzK5NXmA

Ivanov, V., & Chu, J. (2008). Applications of microorganisms to geotechnical engineering for bioclogging and biocementation of soil in situ. *Reviews in Environmental Science and Biotechnology*, *7*(2), 139–153.

Johari, M., Zeyad, A. M., Muhamad Bunnori, N., &Ariffin, K. S. (2012). Engineering and transport properties of high-strength green concrete containing high volume of ultrafine palm oil fuel ash. *Construction and Building Materials*, *30*, 281–288.

Jo, H. Y., Katsumi, T., Benson, C. H., & Edil, T. B. (2001). Hydraulic conductivity and swelling of nonprehydrated GCLs permeated with single-species salt solutions.*Journal of Geotechnical and Geoenvironmental Engineering*, *127*(7), 557–567.

Kabir, M. H., & Taha, M. R. (2004). Assessment of physical properties of a granite residual soil as an isolation barrier. *Electronic Journal of Geotechnical Engineering, 9. 1.*

Kalkan, E. (2006). Utilization of red mud as a stabilization material for the preparation of clay liners. *Engineering Geology*, *87*(3), 220–229.

Kalkan, E., & Bayraktutan, M. S. (2008). Geotechnical evaluation of Turkish clay deposits: A case study in Northern Turkey. *Environmental Geology*, *55*(5), 937–950.

Kaya, A., & Durukan, S. (2004). Utilization of bentonite-embedded zeolite as clay liner. *Applied Clay Science*, *25*(1), 83–91.

Kayabali, K. (1997). Engineering aspects of a novel landfill liner material: bentonite-amended natural zeolite. *Engineering Geology*, *46*(2), 105–114.

Khire, M. V., Benson, C. H., &Bosscher, P. J. (1997). Water balance modelling of earthen final covers.*Journalof Geotechnical and Geoenvironmental Engineering*, *123*(8), 744–754.

Kholmatov, K., Khashimova, D., Wu, W., &Musaev, M. (2010). Geotechnical site characterization of municipal solid waste landfill in Uzbekistan.In *Advances Environmental Geotechnics* (pp. 571–577). Springer Berlin Heidelberg.Retrieved from http://link.springer.com/chapter/10.1007/978-3-642-04460-1_57

Kjeldsen, P., Barlaz, M. A., Rooker, A. P., Baun, A., Ledin, A., & Christensen, T. H. (2002). Present and long – term composition of MSW landfill leachate: A review. *Critical Reviews in Environmental Science and Technology*, *32*(4), 297–336.

Kleppe, J. H., & Olson, R. E. (1985). Desiccation cracking of soil barriers. *Hydraulic Barriers in Soil and Rock*, 263–275.

Kodikara, J. K., Barbour, S. L., & Fredlund, D. G. (2000). Desiccation cracking of soil layers. *Unsaturated Soils for Asia*, *90*(5809), 139.

Koivula, M. P., Kujala, K., Rönkkömäki, H., &Mäkelä, M. (2009). Sorption of Pb (II), Cr (III), Cu (II), As (III) to peat, and utilization of the sorption properties in industrial waste landfill hydraulic barrier layers. *Journal of Hazardous Materials*, *164*(1), 345–352.

Komilis, D. P., Ham, R. K., & Stegmann, R. (1999). The effect of municipal solid waste pre-treatment on landfill behaviour: A literature Review. Waste Management and Research, 17(1), 10 – 19.

Krishna, R., & Shivashankar, R. (2011). Geotechnical properties of shedi soil affected byalkali contamination. *International Journal of Environmental Protection, 1(4),* 45 – 52.

Kumar, A., Walia, B. S., & Mohan, J. (2006). Compressive strength of fiber reinforced highly compressible clay. *Construction and Building Materials, 20*(10), 1063– 1068.

Lambe, T. W. (1958). The structure of compacted clay. *Journal of the Soil Mechanics and Foundations Division, ASCE, 84,* 1–34.

Lamb, T. W., & Whitman, R. V. (1979). *Soil Mechanics, SI Version*. Wiley, New York.

Lee, J.-M., Shackelford, C. D., Benson, C. H., Jo, H.-Y., & Edil, T. B. (2005). Correlating index properties and hydraulic conductivity of geosynthetic clay liners. *Journal of Geotechnical and Geoenvironmental Engineering*, *131*(11), 1319–1329.

Li, J., Xue, Q., Wang, P., & Liu, L. (2013). Influence of leachate pollution on mechanical properties of compacted clay: A case study on behaviors and mechanisms. *Engineering Geology, 167,* 128–133.

Ma, L. H., Zeng Z. Z., Sun, Z. Z., Wang, S. X., (2009). Comparative experiment on permeability of clear water and leachate in two kinds of loses cushions. *J. Anhui Agric Sci.* 37(13) 6089 – 6091.

Ministry of Natural Resources and Environment (2010).Environmental requirements: A guide for investors. Department of Environment, Ministry of NaturalResources and Environment,WismaSumberAsli, Precinct 4 FederalGovernment Administrative Centre 62574Putrajaya, 11th ed., pp: 82

Mitchell, J. K. (1976). *Fundamentals of soil behavior*. Wiley New York. Retrieved from http://sutlib2.sut.ac.th/sut_contents/H93569.pdf

Mitchell, J. K., Hooper, D. R., & Campanella, R. G. (1900). Permeability of compacted clay. *Journal of Soil Mechanics & Foundations Div*, *92*(SM5, Proc Paper 490). Retrieved from http://trid.trb.org/view.aspx?id=121723

Mitchell, J. K., & Soga, K. (1976). *Fundamentals of soil behavior* (p. 422). New York:Wiley.

Moses, G., & Afolayan, J. O. (2011). Compacted foundry sand treated with cement kilndust as hydraulic barrier material. *Electronic Journal of Geotechnical Engineering*, 16, 337 – 355.

Moses, G., Oriola, F. O. P., Afolayan J. O. (2013). The impact of compactive effort on the long term hydraulic conductivity of compacted foundry sand treated with bagasse ash and permeated with municipal solid waste landfill leachate. *Frontiers in Geotechnical Engineering (FGE)*, 2 (10) 7 – 15.

Moses, G., & Afolayan, J. O. (2013). Desiccation-Induced Volumetric Shrinkage of Compacted Foundry Sand Treated with Cement Kiln Dust. *Geotechnical and Geological Engineering*, *31*(1), 163–172.

Nithiaraj, R., Ting, W. H., & Balasubramaniam, A. S. (1996). Strength parameters of residual soils and application to stability analysis of anchored slopes. *Geotechnical Engineering*, 27(2), 55 – 81.

Nwaiwu, C. M. O. (2009). Statistical distributions of hydraulic conductivity from reliability analysis data. *Geotechnical and Geological Engineering*, *27*(1), 169–179.

Oakley, R. E. (1987). Design and performance of earth-lined containment systems. In *Geotechnical Practice for Waste Disposal'87* (pp. 117–136). Retrieved from http://cedb.asce.org/cgi/WWWdisplay.cgi?52510

Ola, S. A. (1977). The potentials of lime stabilization of lateritic soils. *Engineering Geology*, *11*(4), 305–317.

Ören, A. H., & Özdamar, T. (2013). Hydraulic conductivity of compacted zeolites. *Waste Management & Research*, *31*(6), 634–640.

Oriola, F. O. P., & Moses, G. (2011). Compacted black cotton soil treated with cement kiln dust as hydraulic barrier material. *Am J Sci. Ind Res*, *2*(4), 521–530.

Osinubi, K. J., Eberemu, A. O., Bello, A. O., &Adzegah, A. (2012). Effect of fines content on the engineering properties of reconstituted lateritic soils in waste containment application.*Nigerian Journal of Technology (NIJOTECH)*, *31*(3), 277–287.

Osinubi, K. J., & Eberemu, A. O. (2009). Desiccation-induced shrinkage of compacted lateritic soil treated with bagasse ash. In *The twenty-fourth international conference on solid waste technology and management CD-ROM* (pp. 15–18).

Osinubi, K. J., & Eberemu, A. O. (2013). Hydraulic conductivity of compacted lateritic soil treated with bagasse ash. *International Journal of Environment and Waste Management*, *11*(1), 38–58.

Osinubi, K. J., Eberemu, A. O., & Amadi, A. A. (2006). Compacted lateritic soil treated with blast furnace slag as hydraulic barriers in waste containment systems. *International Journal of Risk Assessment and Management*, *13*(2), 171–189.

Osinubi, K. J., & Eberemu, O. A. (2006). Hydraulic conductivity of compacted lateritic soil treated with blast furnace slag. *Electron Journal of Geotechnical Engineering (EJEG)* 32(1), 222- 231.

Osinubi, K. J., & Moses, G. (2011). Compacted foundry sand treated with bagasse ash as hydraulic barrier material. In *Geo-Frontiers 2011@ Advances in Geotechnical Engineering* (pp. 915-925). ASCE.

Osinubi, K. J., & Moses, G. (2013). Hydraulic performance of compacted foundry sandbagasse ash mixture permeated with municipal solid waste leachate. Frontiers in Geotechnical Engineering (FGE) 2(1), 7 – 15.

Osinubi, K. J., & Nwaiwu, C. M. (2005). Hydraulic conductivity of compacted lateritic soil. *Journal of Geotechnical and Geoenvironmental Engineering*, *131*(8), 1034–1041.

Osinubi, K. J., & Nwaiwu, C. M. (2006). Design of compacted lateritic soil liners and covers. *Journal of Geotechnical and Geoenvironmental Engineering*, *132*(2), 203–213.

Osinubi, K. J., & Nwaiwu, C. M. O. (2008). Desiccation-induced shrinkage in compacted lateritic soils. *Geotechnical and Geological Engineering*, *26*(5), 603–611.

Ozcoban, M. S., Cetinkaya, N., Celik, S. O., Demirkol, G. T., Cansiz, V., &Tufekci, N. (2013). Hydraulic conductivity and removal rate of compacted clays permeated withlandfill leachate. *Desalination and Water Treatment*,14(2), 1-10.

Oztoprak, S., & Pisirici, B. (2011). Effects of micro structure changes on the macro behaviour of Istanbul (Turkey) clays exposed to landfill leachate. *Engineering Geology*, 121(3), 110 – 122.

Petrov, R. J., & Rowe, R. K. (1997). Geosynthetic clay liner (GCL)-chemical compatibility by hydraulic conductivity testing and factors impacting its performance. *CanadianGeotechnical Journal*, *34*(6), 863–885.

Phani Kumar, B. R., & Sharma, R. S. (2004). Effect of fly ash on engineering properties of expansive soils. *Journal of Geotechnical and Geoenvironmental Engineering*, *130*(7), 764–767.

Qian, X., Koerner, R. M., & Gray, D. H. (2002). *Geotechnical aspects of landfill design and construction* (Vol. 717). Prentice Hall New Jersey. Retrieved from http://www.lavoisier.fr/livre/notice.asp?id=OR2WORA3AOXOWS

Qiang, X., Hai-jun, L., Zhen-ze, L., & Lei, L. (2014). Cracking, water permeability and deformation of compacted clay liners improved by straw fiber. *Engineering Geology*, *178*, 82-90.

Raghab, S. M., Abd El Meguid, A. M., &Hegazi, H. A. (2013). Treatment of leachate from municipal solid waste landfill. *HBRC Journal*, *9*(2), 187–192.

Rahman, Z. A., Yaacob, W. Z. W., Rahim, S. A., Lihan, T., Idris, W. M. R., & Sani, W. N. F. (2013). Geotechnical Characterisation of Marine Clay as Potential Liner Material. *SainsMalaysiana*, *42*(8), 1081–1089.

Rifai, S. M. (2000). Impact of polypropylene fibers on desiccation cracking and hydraulic conductivity of compacted clay soils. Retrieved from http://digitalcommons.wayne.edu/dissertations/AAI9992261/

Rowe, R. K., Quigley, R. M., & Booker, J. R. (1995). *Clayey barrier systems for waste disposal facilities*. E & FN Spon. Retrieved from http://www.getcited.org/pub/103216515

Rowe, R. K., Quigley, R. M., Brachman, R. W., Booker, J. R., &Brachman, R. (2004). *Barrier systems for waste disposal facilities.*Spon Press. Retrieved from http://www.cabdirect.org/abstracts/20043114094.html

Rubinos, D., Spagnoli, G., &Barral, M. T. (2013). Assessment of bauxite refining residue (red mud) as a liner for waste disposal facilities. *International Journal of Mining, Reclamation and Environment*, 15(4), 1–20.

Ryan, C. R. (1987). Vertical barriers in soil for pollution containment. *In Geotechnical practice for waste disposal* (pp.182 – 204). ASCE. Retrieved from http://cedb.asce.org/cgi/WWWdisplay.cgi?8701733

Safiuddin, M., Abdus Salam, M., &Jumaat, M. Z. (2011). Utilization of palm oil fuel ash in concrete: A review.*Journal of Civil Engineering and Management*, *17*(2), 234–247.

Sahu, V., & Gayathri, V. (2014). Geotechnical characterization of two low lime Indian flyashes and their potential for enhanced utilization.*An International JournalCivil Engineering and Urban Planning*, 1(1), 22-33

Sata, V., Jaturapitakkul, C., &Kiattikomol, K. (2004). Utilization of palm oil fuel ash in high-strength concrete. *Journal of Materials in Civil Engineering*, *16*(6), 623–628.

Schackelford, C. D. (1994). Waste-soil interactions that alter hydraulic conductivity. *ASTM Special Technical Publication*, *1142*, 111–111.

Seed, H. B., & Chan, C. K. (1960).Structure and strength characteristics of compacted clays. Institute of Transportation and Traffic Engineering, University of California.

Shackelford, C. D., Benson, C. H., Katsumi, T., Edil, T. B., & Lin, L. (2000). Evaluating the hydraulic conductivity of GCLs permeated with non-standard liquids. *Geotextiles andGeomembranes*, *18*(2), 133–161.

Sims, J. E., Elsworth, D., & Cherry, J. A. (1996). Stress-dependent flow through fractured clay till: A laboratory study. *Canadian Geotechnical Journal*, *33*(3), 449–457

Singh, S., & Prasad, A. (2007). Effects of chemicals on compacted clay liner.*Electronic Journal of Geotechnical Engineering*, *12*(3), 1-15.

Sinsiri, T., Kroehong, W., Jaturapitakkul, C., &Chindaprasirt, P. (2012). Assessing the effect of biomass ashes with different finenesses on the compressive strength of blended cement paste. *Materials & Design*, *42*, 424–433.

Sivapullaiah, P. V., & Baig, M. (2011). Gypsum treated fly ash as a liner for waste disposal facilities. *Waste Management*, *31*(2), 359–369.

Sridharan, A., & Prakash, K. (1998). Mechanism controlling the shrinkage limit of soils.*ASTM Geotechnical Testing Journal*, *21*(3), 240–250.

Sunil, B. M., Shrihari, S., & Nayak, S. (2008). Soil-leachate interaction and their effects onhydraulic conductivity and compaction characteristics. In*the 12th International Conference of International Association, for computer methods & Advances in Geomechanics (IACMAG)* (pp. 1–6). Retrieved from http://www.civil.iitb.ac.in/~dns/IACMAG08/pdfs/I19.pdf

Taha, M. R., & Kabir, M. H. (2003). Sedimentary residual soils as a hydraulic barrier in waste containment systems. In *Second International Conference on Advances in Soft Soil Engineering Technology, Putrajaya, Malaysia* (pp. 895–904).

Taha, M. R., & Kabir, M. H. (2005). Tropical residual soil as compacted soil liners. *Environmental Geology*, *47*(3), 375–381.

Taha, M. R., & Taha, O. M. E. (2012). Influence of nano-material on the expansive and shrinkage soil behavior. *Journal of Nanoparticle Research*, *14*(10), 1–13.

Tahir, T. A., & Hamid, F. S. (2012). Vermicomposting of two types of coconut wastes employing Eudrilus eugeniae: a comparative study. *International Journal ofRecycling of Organic Waste in Agriculture*, *1*(1), 1–6.

Tan, B.K., (2004) Country case study: engineering geology of tropical residual soils in Malaysia.

Tan, B. K.,& Ong, C. Y. (1993). Physico-chemical properties of granitic soilsalong the Ipoh-ChangkatJering Expressway, Perak, Malaysia. In *Proc. 11th SEA. Geotechnical Conference* (pp. 217-221).

Tangchirapat, W., & Jaturapitakkul, C. (2010). Strength, drying shrinkage, and water permeability of concrete incorporating ground palm oil fuel ash. *Cement and Concrete Composites*, *32*(10), 767–774.

Tangchirapat, W., Jaturapitakkul, C., &Chindaprasirt, P. (2009). Use of palm oil fuel ash as a supplementary cementitious material for producing high-strength concrete.*Construction and Building Materials*, *23*(7), 2641–2646.

Tang, C.-S., Cui, Y.-J., Shi, B., Tang, A.-M., & Liu, C. (2011). Desiccation and crackingbehaviour of clay layer from slurry state under wetting–drying cycles. *Geoderma*,*166*(1), 111–118.

Tatsi, A. A., Zouboulis, A. I., Matis, K. A., & Samaras, P. (2003). Coagulation–flocculation pretreatment of sanitary landfill leachates. *Chemosphere*, *53*(7), 737–744.

Tay, J.-H. (1990). Ash from oil-palm waste as a concrete material. *Journal of Materials in Civil Engineering*, *2*(2), 94–105.

Turan, N. G., & Gümücsel, E. B. (2012). Utilizing Natural Liner Materials for Heavy Metal Removal in Simulated Landfill Conditions. *CLEAN–Soil, Air, Water*. Retrieved from http://onlinelibrary.wiley.com/doi/10.1002/clen.201100604/full

Uppot, J. O., & Stephenson, R. W. (1989). Permeability of clays under organic permeants. *Journal of Geotechnical Engineering*, *115*(1), 115–131.

Vanapalli, S. K. (2008). *Evaluation of the Performance of Soil Liners using the Mechanics of Saturated and Unsaturated soils*.(Doctoral dissertation, University of Ottawa). Retrieved from http://www.geotechlinks.com/Links/JoelMateoThesis-Performance-Soil-Liners.pdf

Wan Zuhairi, W. Y., Samsudin, A. R., & Kong, T. B. (2008). The sorption distribution coefficient of lead and copper on the selected soil samples from Selangor. *Bulletin of the Geological Society of Malaysia*, *54*, 21–25.

Yesiller, N., Miller, C. J., Inci, G., &Yaldo, K. (2000). Desiccation and cracking behavior of three compacted landfill liner soils. *Engineering Geology*, *57*(1), 105–121.

Young, T. M. (2006). Natural Attenuation of Contaminants in Soils. *Vadose Zone Journal*, *5*(3), 913-914.

Yusof, M., Nizar, K., & Yusof, M. F. (2007). Correlations of physical and chemical properties of eastern granitic soils of Peninsular Malaysia. Retrieved from http://eprints.uthm.edu.my/1879/

Zarina, Y., Al Bakri, A. M., Kamarudin, H., Nizar, I. K., &Rafiza, A. R. (2013).

Review on the various ash from palm oil waste as geopolymermaterial. *Rev. Adv. Mater. Sci*, *34*, 37–43.

Zin, M., Shaylinda, N., Abdul Aziz, H., Adlan, M. N., &Ariffin, A. (2012). Characterization of leachate at Matang landfill site, Perak, Malaysia. *Academic Journal of Science*, *1*(2), 317–322.