



**UNIVERSITI PUTRA MALAYSIA**

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

**ABUBAKAR SADIQ MUHAMMED**

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**By**

**ABUBAKAR SADIQ MUHAMMED**

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

**February 2015**

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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

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

**By**

**ABUBAKAR SADIQ MUHAMMED**

**February 2015**

**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 capacity mineral 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  $6.51 \times 10^{-9}$ ,  $2.23 \times 10^{-10}$ ,  $2.31 \times 10^{-11}$  and  $1.31 \times 10^{-9}$  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 of moulding water content in which minimum set 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 leachate which 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 GRANIT TERPADAT  
YANG DIRAWAT DENGAN ABU BAHAN API KELAPA SAWIT SEBAGAI  
PENGHALANG HIDRAULIK DI TAPAK PELUPUSAN SANITARI**

Oleh

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**Februari 2015**

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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 pepadatan (proktor standard dan proktor diubahsuai). Ujian-ujian terhadap kedua-dua jenis tanah semula jadi dan tanah campuran POFA termasuk ujian fizikal (kandungan lembapan, graviti tentu, analisis ayakan, had Atterberg, pepadatan), 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 lompong 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%. Bagi usaha pemadatan proctor diubahsuai dan +2% OMC, nilai kekonduksian hidraulik  $6.51 \times 10^{-9}$ ,  $2.23 \times 10^{-10}$ ,  $2.31 \times 10^{-11}$  dan  $1.31 \times 10^{-9}$  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 kandungan POFA. 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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I certify that a Thesis Examination Committee has met on 17 February 2015 to conduct the final examination of Abubakar Sadiq Muhammed on his thesis entitled "Suitability of using Compacted Granite Residual Soil Treated with Palm Oil Fuel Ash as Hydraulic Barrier in Sanitary Landfill" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.

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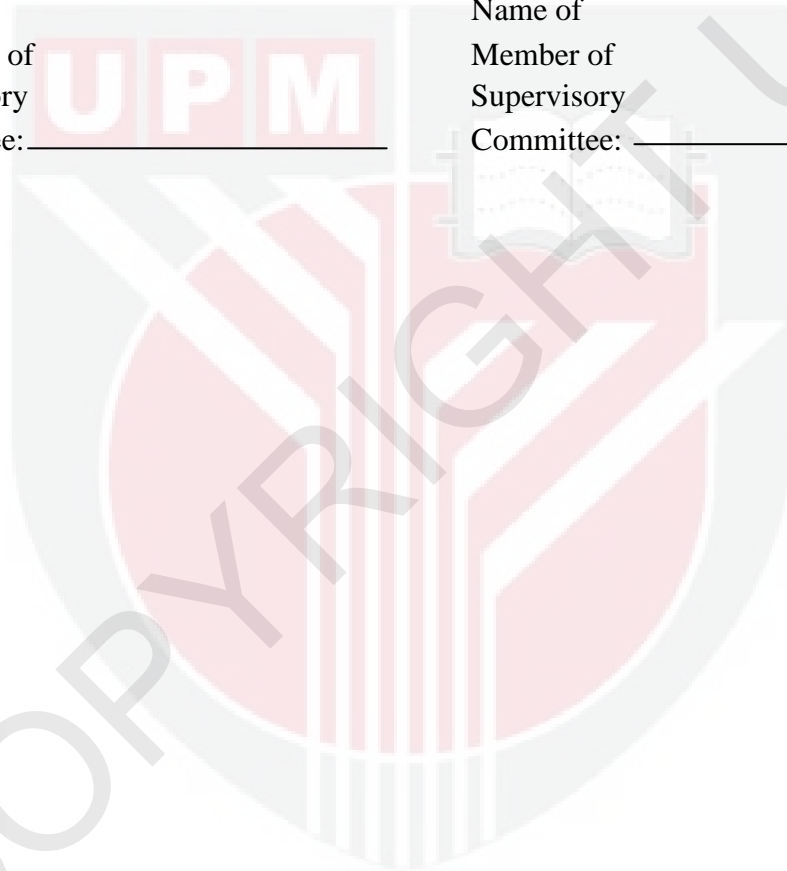
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## TABLE OF CONTENTS

	<b>Page</b>
<b>ABSTRACT</b>	i
<b>ABSTRAK</b>	iii
<b>ACKNOWLEDGEMENTS</b>	v
<b>APPROVAL</b>	vi
<b>DECLARATION</b>	viii
<b>LIST OF TABLES</b>	xii
<b>LIST OF FIGURES</b>	xiii
<b>LIST OF ABBREVIATIONS</b>	xiv
<b>CHAPTER</b>	
<b>1 INTRODUCTION</b>	<b>1</b>
1.1 Problem Statement	3
1.2 Aim and Objectives	3
1.3 Scope and Limitation	4
1.4 Justification	4
1.5 Thesis Organization	4
<b>2 LITERATURE REVIEW</b>	<b>6</b>
2.0 Introduction	7
2.1 Composite Material for Hydraulic Barrier in Landfill	11
2.2 General Barrier Specifications	11
2.3 Shrinkage and Cracking Mechanism	12
2.3.1 Volumetric Shrinkage Strain	13
2.3.2 Effect of Additives on Volumetric Shrinkage Strain	15
2.4 Hydraulic Conductivity	16
2.4.1 Compaction Method	16
2.4.2 Moulding Water Content	17
2.4.3 Soil Composition	18
2.5 Unconfined Compressive Strength	18
2.6 Compatibility of Barrier Material	19
2.7 Delineation of Acceptable Zones	21
2.8 Residual Soils and Palm Oil Fuel Ash in Malaysia	22
2.8.1 Formation of Residual Soils	22
2.8.2 Palm Oil Fuel Ash (POFA)	23
<b>3 METHODOLOGY</b>	<b>24</b>
3.0 Introduction	24
3.1 Materials	25
3.2 Methods	26
3.2.1 Physical Properties	27
3.2.2 Chemical Properties	30
3.2.3 Mineralogical and Structural Properties	31
3.2.4 Mechanical Properties	31
3.2.5 Compatibility Studies and Attenuation Analysis	33

<b>4</b>	<b>RESULTS AND DISCUSSION</b>	<b>35</b>
4.0	Introduction	35
4.1	Physical Properties	35
4.2	Chemical Properties of Palm Oil Fuel Ash (POFA) and Granite Residual Soil	37
4.3	Mineralogical Properties	39
4.4	Structural Properties	40
4.5	Mechanical Properties	41
	4.5.1 Hydraulic Conductivity	42
	4.5.2 Volumetric Shrinkage Strain (VSS)	44
	4.5.3 Unconfined Compressive Strength (UCS)	47
4.6	Acceptable Zones for Liner Design	50
4.7	Leachate Compatibility	53
	4.7.1 Attenuation Analyses	55
<b>5</b>	<b>CONCLUSION AND RECOMMENDATIONS</b>	<b>58</b>
5.0	Conclusion	58
5.1	Recommendations	60
	<b>REFERENCES</b>	<b>61</b>
	<b>APPENDICES</b>	<b>76</b>
	<b>BIODATA OF STUDENT</b>	<b>88</b>
	<b>LIST OF PUBLICATIONS</b>	<b>89</b>

## LIST OF TABLES

Table		Page
2.1	Application of waste as composite material used as hydraulic barrier in landfill	7
2.2	Mechanical properties suitable for as a liner material	21
2.3	Major factors affecting soil formation (Bergman and McKnight, 1993)	23
4.1	Physical properties of the soil sample used in the study	34
4.2	Chemical composition of Palm Oil Fuel Ash (POFA) and Granite Residual Soil	37
4.3	Chemical and heavy metal concentration	54





## LIST OF FIGURES

<b>Figure</b>	<b>Page</b>
1.1 Typical section of landfill	2
2.1 Examples of compacted soil liners in (a) Single liner systems; (b) Double liner systems.	7
3.1 Granite residual soil at Hulu Langat, Selangor	24
3.2 Disposal practice of POFA around the factory	25
3.3 Landfill leachate from Jerem sanitary landfill	25
3.4 The position of moulding water content on the compaction curve.	26
3.5 A diagrammatic summary of the tests carried out	26
3.6 Hydraulic conductivity equipment used in carrying out compatibility test	33
4.1 Plots of the soil and soil – POFA mixture on the Cassagrande plasticity Chart	35
4.2 Variation of OMC and MDD with different percentages of POFA using (a) standard proctor and (b) modified proctor compactive energies	36
4.3 X-ray Diffractogram of Granite Residual Soil	38
4.4 X-ray Diffractogram of Palm Oil Fuel Ash	39
4.5 The structural morphology of (a) granite residual soil, (b) palm oil fuel ash (POFA), (c) granite residual soil – POFA mixture	40
4.6 Variation of hydraulic conductivity with moulding water content using standard proctor compactive effort	41
4.7 Variation of hydraulic conductivity with moulding water content using modified proctor compactive effort	42
4.8 Variation of hydraulic conductivity with POFA content at optimum moisture content	43
4.9 Variation of volumetric shrinkage strain with moulding water content using standard proctor compactive effort	44
4.10 Variation of volumetric shrinkage strain with moulding water content using modified proctor compactive effort	44
4.11 Variation of volumetric shrinkage with POFA at optimum moisture content	46
4.12 Variation of unconfined compressive strength with moulding water content using standard proctor compactive effort	47
4.13 Variation of unconfined compressive strength with moulding water content using modified proctor compactive effort	47
4.14 Variation of unconfined compressive strength with POFA at optimum moisture content	49
4.15 Acceptable zone based on hydraulic conductivity for 10% POFA content	50
4.16 Acceptable zone based on volumetric shrinkage for 10% POFA content	50
4.17 Acceptable zone based on unconfined compressive strength for 10% POFA content	51
4.18 Overall acceptable zone for 10% POFA content	52
4.19 Variation of hydraulic conductivity of granite residual soil – POFA mixtures with time (permeated with water and leachate)	53
4.20 Variation removal rate of heavy metals at different percentages of POFA	55

## 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 ( $\text{Mg/m}^3$ )
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 ( $\text{kNm}^2$ )
USCS	Unified Soil Classification System
VSS	Volumetric Shrinkage Strain (%)
XRD	X- Ray Diffraction
XRF	X-Ray fluorescence
ZAV	Zero Air Void ( $\text{Mg/m}^3$ )

## CHAPTER 1

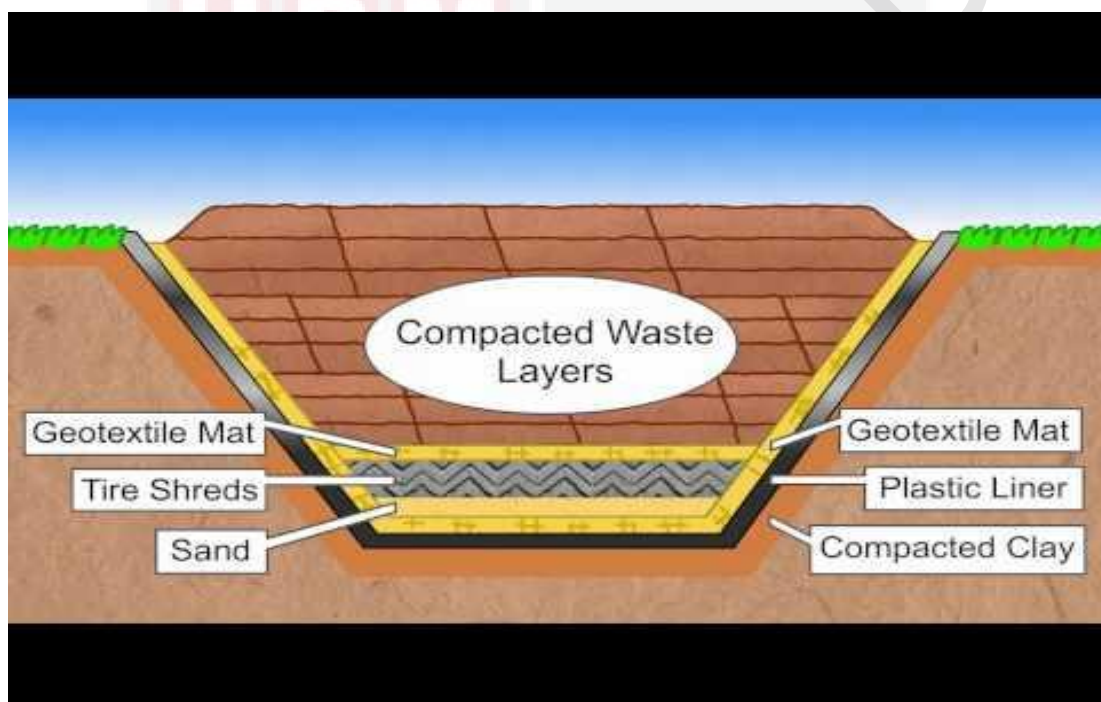
### INTRODUCTION

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  $1 \times 10^{-7}$  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.



[www.google.com.my](http://www.google.com.my)

**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, rice 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.



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