POTENTIAL OF KAOLIN- PALM OIL FUEL ASH MIXTURE AS SUSTAINABLE LANDFILL LINER MATERIAL

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In the Name of ALLAH, the Most Gracious, the Most Merciful.

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ABSTRACT

Contamination of groundwater due to leachate percolating through landfill liner is a potential hazard to human health and the environment. Effective mitigation approaches and imperative research on alternative liner materials could reduce contamination. In this study, an investigation on the potential of kaolin premixed with pulverized palm oil fuel ash (PPOFA) as an alternative mineral liner material is proposed. The investigation was carried out in two stages. Initially, physico-chemical and mechanical characterizations were performed on these materials separately. Then, PPOFA was mixed in stages of 0, 10, 20, and 30 percent by dry mass of the kaolin and were compacted using Standard Proctor. Result from the compaction test showed that 15 percent of PPOFA was found to be the optimum dose for the formulated liner matrix. In the second stage, material characterizations were repeated on the formulated liner matrix followed by performance criteria tests. These tests included heavy metal removal efficiency, chemical sorption, leaching, hydraulic conductivity and column tests. The criteria examined were compared with the standards and previous related research. All the tests were conducted without pH adjustment and were duplicated. Based on sorption tests, Freundlich and Langmuir isotherm models were developed and validated using linear regression and correlation coefficient R. The performance tests recorded high metal ion removal efficiencies of 59 to 99 percent at solution equilibrium pH ranging from 7.64 to 3.00. Freundlich sorption capacities ranged from 0.2063 to 25.64, while the Langmuir monolayer sorption capacity, β ranged from 22.3714 to 52.6316 mgg^{-1}. Besides that, the modelled Freundlich (q_{eFred}) and Langmuir (q_{eLang}) isotherm were relatively well fitted to the experimental (q_{expt}), with correlation coefficients (R) greater than 0.84. Leaching occurred at very low concentrations ranging from 0.003 to 0.19 mgL^{-1} and hydraulic conductivity tests obtained values ranging from 3.14 to 3.66 $\times 10^{-6}$ cms^{-1}. Finally, the column test showed that the hydrodynamic dispersion coefficients (D_L^*) and retardation factors (R_d) ranged between 1.16$\times$ 10^{-3} to 1.11$\times 10^{-5}$ cm^{2}s^{-1} and 17 to 337 respectively. The proposed kaolin-PPOFA liner matrix has been proven to be a promising alternative liner material in ameliorating groundwater contamination from the leachate generated in the landfill.

ABSTRAK

Pencemaran air bumi yang disebabkan oleh penelusan air larut lesap melalui pelapik tapak pelupusan adalah berpotensi membahayakan manusia dan alam sekitar. Pendekatan pencegahan yang berkesan dan penyelidikan yang imperatif mengenai bahan-bahan pelapik ini dapat mengurangkan pencemaran. Menerusi kajian ini, satu penyiasatan telah dicadangkan ke atas potensi campuran kaolin dengan serbuk abu bahan bakar kelapa sawit (*PPOFA*) sebagai alternatif kepada bahan mineral pelapik. Penyelidikan ini telah dijalankan dalam dua peringkat. Pada mulanya, pencirian kimia-fizikal dan mekanikal telah dilakukan ke atas bahan-bahan ini secara berasingan. Kemudian, bahan *PPOFA* telah dicampurkan pada tahap 0, 10, 20, 30 peratus jisim kering kaolin dan dipadatkan menggunakan kaedah Piawaian *Proctor*. Melalui ujian pemadatan, *PPOFA* 15 peratus merupakan dos optimum untuk matriks pelapik yang telah diformulasikan. Pada peringkat kedua, pencirian bahan telah diulangi pada matriks pelapik yang diformulasikan diikuti dengan ujian prestasi kriteria. Ujian-ujian ini termasuklah kecekapan penyingkiran logam berat, penyerapan kimia, larut lesap, kekonduksian hidraul dan ujian turus. Kriteria yang dianalisa telah dibandingkan dengan piawaian dan penyelidikan sebelumnya yang berkaitan. Kesemua ujian telah diulang sebanyak dua kali tanpa mengubah nilai pH. Berdasarkan ujian penyerapan, model lengkung sesuhu Freundlich dan Langmuir telah dihasilkan dan disahkan menggunakan kaedah regresi lelurus dan pekali korelasi R. Prestasi ujian merekodkan nilai kecekapan penyingkiran ion logam yang tinggi daripada 59 hingga 99 peratus pada keseimbangan pH larutan antara 7.64 hingga 3.00. Kapasiti erapan Freundlich bernilai antara 0.2063 hingga 25.64, manakala nilai kapasiti erapan ekalapisan Langmuir, β adalah antara 22.3714 hingga 52.6316 mgg^{-1}. Di samping itu, model lengkung sesuhu Freundlich (q_{eFred}) dan Langmuir (q_{eLang}) yang dihasilkan memberi nilai yang menghampiri nilai eksperimen (q_{expt}), dengan pekali korelasi (R) lebih besar daripada 0.84. Larutlesapan berlaku pada kepekatan yang sangat rendah iaitu antara 0.003 hingga 0.19 mgL^{-1} dan ujian kekonduksian hidraul memberi nilai antara 3.14 hingga 3.66×10^{-6} cms^{-1}. Akhir sekali, ujian turus menunjukkan nilai pekali serakan hidrodinamik (D_L^*) dan faktor perencatan (R_d) yang masing-masing bernilai antara 1.16×10^{-3} ke 1.11×10^{-5} cm^2s^{-1} dan 17 ke 337. Matriks pelapik kaolin-PPOFA yang dicadangkan telah dibuktikan sebagai alternatif bahan pelapik yang berpotensi dalam membendung pencemaran air bumi dari proses larut lesap yang dihasilkan di tapak pelupusan.

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LIST OF ABBREVIATIONS

AR	-	Analytical reagent
BAET	-	Batch adsorption equilibrium test
BET	-	Brunauer Emmet Teller
BS	-	British Standard
BSCS	-	British Soil Classification System
BSI	-	British Standard Institution
BTC	-	Breakthrough curve
CCL	-	Compacted clay liner
CE	-	Cation Exchange
CEC	-	Cation Exchange Capacity
CSH	-	Calcium Silicate Hydrate
DDL	-	Diffused double layer
DIW	-	Deionized Water
DW	-	Distilled water
EC	-	Electrical conductance
EDS	-	Energy dispersive spectroscopy
EDX	-	Energy Dispersive X-Ray Analyzer
EDXRF	-	Energy Dispersive X-Ray Fluorescence spectrometer
FAAS	-	Flame Atomic Absorption Spectrophotometer
GHG	-	Greenhouse gases
GPOFA	-	Ground POFA
GRG	-	Generalized Reduced Gradient
HDTMA	-	Hexadecyltrimethlammomium
HFC	-	Hydrofluorocarbons
ICDD	-	International Centre for Diffraction Data

LA	-	Los Angeles
LOI	-	Loss on ignition
MH	-	High plasticity silt
MSE	-	Mean square error
OFAT	-	One-factor-at-a time
OPC	-	Ordinary Portland cement
PKS	-	Palm kernel shell
PMF	-	Palm mesocarp fiber
POFA	-	Palm oil fuel ash
PPOFA	-	Pulverized palm oil fuel ash
PSA	-	Particle size analyser
PV	-	Pore volume
pzc	-	Point of zero charge
SA	-	Surface area
SEM	-	Scanning electron-microscope
SSE	-	Sum of squares of the error
SWGM	-	Solid waste management
TPPOFA	-	Treated PPOFA
W/B	-	Water-binder ratio
XRD	-	X-Ray Diffractometer
ZAV	-	Zero air void

LIST OF SYMBOLS

a - Cross sectional area of manometer tube (cm^2)

A - Cross sectional area of compacted liner sample (cm^2)

C_c - Coefficient of curvature

C_e - Solute concentration in solution at equilibrium (mgL^{-1})

C_u - Coefficient of uniformity

C_{eff} - Effluent concentration (mgL^{-1})

C_{inf} - Influent concentration (mgL^{-1})

C_o - Initial concentration (mgL^{-1})

C_R - Relative compaction (%)

CEC - Cation Exchange Capacity (cmol(+)/kg = meq/100g)

d_{50} - Mean particle diameter (µm)

D^* - Effective diffusion coefficient (cm^2s^{-1})

D_h - Hydrodynamic dispersion coefficient (cm^2s^{-1})

D_L - Longitudinal hydrodynamic dispersion coefficient (cm^2s^{-1})

D_m - Mechanical dispersion coefficient (cm^2s^{-1})

e - Void ration (dimensionless)

EC - Electrical conductance ($mScm^{-1}$)

EC_{eff} - effluent electric conductance ($mScm^{-1}$)

EC_{inf} - Influent electric conductance ($mScm^{-1}$)

EC_o - Initial electrical conductance ($mScm^{-1}$)

EC_e - Equilibrium electrical conductance ($mScm^{-1}$)

EDS - Energy Dispersive Spectroscopy (2θ)

EDX - Energy Dispersive X-ray (2θ)

f_{oc} - Organic carbon (%)

f_{om}` - Organic matter (%)

F_d - Diffusive flux (mgcm^{-2}sec^{-1})

F_M - Dispersive flux (mgcm^{-2}sec^{-1})

F_T - Total mass flux (mgcm^{-2}sec^{-1})

F_V - Advective flux (mgcm^{-2}sec^{-1})

H_1 - Height from effluent point to the upper mark (cm)

H_2 - Height from effluent point to the lower mark (cm)

H_3^* - Distance of third calibration point from the upper mark (cm)

H_i - Initial head of the de-aired DW in the manometer (cm)

H_f - Subsequent head of the de-aired DW estimated in the Manometer at the end of a particular period of time (cm)

i - Hydraulic gradient (dimensionless)

I_P - Plasticity index (%)

k - 1-D hydraulic conductivity (cms^{-1})

k_{ave} - Average hydraulic conductivity (cms^{-1})

$k_{\max}$ - Maximum recorded hydraulic conductivity (cms^{-1})

K_F - Freundlich isotherm coefficient

l - Length of sample under test (cm)

LOI - Loss on ignition (%)

n - Porosity (dimensionless)

M_S - Mass of dry liner material add to the aqueous solution (g)

N - Freundlich isotherm constant (dimensionless)

pH_e - Equilibrium pH

pH_{eff} - Effluent pH

pH_{inf} - Influent pH

pH_o - Initial pH

P_L - Peclet number (Dimensionless)

PV - Pore volume (cm^3)

$q_e^{'}$ - Solute removal efficiency (%)

q_e - Mass of contaminant sorbed per unit dry mass of the solid (mgg^{-1})

q_{expt} - Measured mass of contaminant sorbed per unit dry mass of the solid (mgg^{-1})

$q_{eFred.}$ - Freundlich mass of contaminant sorbed per unit dry mass of the solid (mgg^{-1})

$q_{eLang.}$ - Langmuir mass of contaminant sorbed per unit dry mass of the solid (mgg^{-1})

r - Lnear correlation coefficients

R^2 - Coefficient of determination

R_d - Retardation factor (dimensionless)

SA - Surface area (m^2g^{-1})

t - Solute transport time in the porous medium (sec)

t_i - Start time of test (sec)

t_f - Subsequent estimated time corresponding to H_f (sec)

Δt - Difference between t_f and t_i (sec)

T_R - Dimensionless time factor

V_W - Volume of solution containing an initial concentration, C_o (L)

V_s - Seepage or average linear velocity (cms^{-1})

w_L - Liquid limit (%)

w_{opt} - Optimum water content (%)

w_P - Plastic limit (%)

W - Mass of adsorbent (g)

XRD - X-Ray Diffraction (count per sec / cps)

Z - Distance in the direction of contaminant flow (cm)

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CHAPTER 1

INTRODUCTION

1.1 Background of the Problem

In recent years the acceleration in urbanization of many countries worldwide has led to interest in various fields of research. One area is in the solid waste management (SWM) (Foo *et al.*, 2013; Karagiannidis *et al.*, 2010; Chen *et al.*, 2010; Guo *et al.*, 2010). Solid wastes are generally being generated by human activities. These wastes may be classified as municipal wastes from commercial and residential sources; hazardous wastes from hospitals and radioactive plants; as well as agricultural and industrial wastes. Colossal part of these wastes ends up in landfills as they are characterized by their unhygienic nature. Thus, solid wastes are generally unacceptable to the society.

Usually, open dumping or unlined landfilling of generated solid wastes is characterized by uncontrolled and heterogeneous disposal. Though waste dumping is regarded cheap to manage, it is highly pervasive and environmentally unacceptable to the teaming society. It has also been recognized as one of the contributing factors to unhealthy environment. Hence, open dumping could be classified as unsuitable technique militating against the yearnings and aspirations for green and sustainable environment. As such, nowadays unlined landfilling is being replaced by sanitary landfill. The sanitary landfilling of solid waste may be categorized as land disposal technique, and is commonly known as “engineered sanitary” landfill systems (Ayomoh, *et al.*, 2008; Manfredi and Christensen, 2009; Abu Amr *et al.*, 2012).

Even though engineered landfilling approach has been reported as inappropriate (Chang *et al.*, 2009), to date the technique still represents one of the primary component in integrated and sustainable waste management techniques (Galante *et al.*, 2010; Perkoulidis *et al.*, 2010; Agamuthu and Fauziah 2010). The prime objective of incorporating engineered landfill in integrated waste management system is to significantly limit the dangerous health impact from the generated wastes on the society. More to this is that it enhances sustainable and eco-friendly environment (Rajesh and Viswanadham, 2011).

Generally, disposed solid wastes in landfill undergo both biological and chemical degradation. Both processes take place in the presence of water percolated through solid waste deposited. The final aqueous-waste effluent discharged is referred to as leachates. Although engineered landfill techniques have tremendously reduced the paranoid of groundwater contamination from the generated leachates (Benbelkacem *et al.,*2010; Foo *et al.*, 2013), the formation and management of the aqueous contaminant still pose major problem, thus demand great attention (Mendoza and Izquierdo, 2008; Kim et al., 2009; Umar *et al.*, 2010). For instance, leachate is prone to be a veritable source of non-biodegradable and toxic heavy metals ions disposition. Heavy metals, such as zinc (Zn), lead (Pb), cadmium (Cd), Nickel (Ni), Mercury (Hg) and copper (Cu) constitute part of these contaminant solutes. As such, they are considered toxic to human health and the environment at large (Chalermyanont *et al.*, 2009; Zhang *et al.*, 2013; Silva *et al.*, 2013).

Judging from the characteristics and age of the waste materials deposited in landfills, chemical ionization of heavy metals may as well be characterized by different level of toxicity (Östman, 2008; Zhang *et al.*, 2013). Also, some portion of the toxic aqueous pollutants may escape transfer to treatment plant and be transported through the liner located somewhere within the shallow unsaturated zone of the subsoil (Zhang *et al.*, 2012). Thereafter, the liquid waste may get in contact with the surrounding environments and renders it contaminated. Principally the surrounding environments include the valuable but infinite groundwater resource. Research has shown that leachate is liable to adversely transform the environment through the creation of imbalance and inhabitable ecosystem (Foo and Hameed, 2009; Silva *et al.*, 2013).

Besides, further decomposition of some chemical compounds present in the leachate may contribute significantly to the emission of obnoxious odor from within the landfill site. If uncontrolled, such emission may render the surrounding air polluted. The release of heat trapping greenhouse gases (GHG) such as carbon dioxide (CO_2) and methane (CH_4) are also witnessed (Zhang *et al.*, 2013; Ahmari and Zhang, 2013). Other non-environmentally friendly gaseous emissions such as ammonia (NH_4), nitrous oxide (N_2O) and hydrofluorocarbons (HFCs) are also released from the fill. As obtainable in groundwater pollution, the consequential effects of air pollution include adverse human health related implications such as cancer and air borne diseases. From the aforementioned, further research specifically on sustainable earthen landfill liner material is eminent. With this the adverse environmental impacts of the liquefied waste could be effectively ameliorated and at the same time ensure that the liner keep serving as functional integral part of solid waste management system.

The present situation in landfill liner material research shows that there are concerted efforts specifically geared toward the use of minerals as sustainable landfill liner material (Musso *et al.*, 2010; Koutsopoulou *et al.*, 2010; Quaghebeur *et al.*, 2013). Generally, landfill liners constructed from the use of only one material such as soil is not suitable for use as solid waste repository. It may often not meet the regulatory performance requirement of hydraulic conductivity and related contaminants attenuation (Chalermyanont *et al.*, 2009). Hence, soil liners are predominantly design of compacted composite clay material and formed the lower integral part which directly overlies the natural geologic structure (Fall *et al.*, 2009; Guyonnet *et al.*, 2009; Silva and Almanza, 2009; Lange *et al.*, 2010).

More specific, Fall *et al.* (2009) have shown great interest in the use of minerals as landfill liner material. They took the advantage of the strong negatively charged surface energy carried by soil particles. Hence, reactive mineral liner materials are used as trapping mechanism of the positively charged solute components of the contaminants. Usually, these solutes are often trapped and immobilized while migrating through the pore spaces of the hydrated compacted clay liner (CCL) (Chalermyanont *et al.*, 2009; Silva and Almanza, 2009; Koutsopoulou *et al*., 2010). The end result was the effective reduction and mitigation of groundwater pollution due to toxic heavy metal ions leached from the solid waste disposed in landfills.

Furtherance to the use of CCL, innovative researches are being carried out on the potential and viability of amending clayey soils with waste materials. The matrixes formed are often used as an alternative composite mineral liner material. These waste materials include ashes from incinerator plants (Travar *et al.*, 2009) as well as bottom and fly ashes produced as by-product from the burning of coal in power generating plants (Nhan *et al.*, 1997; Kayabalı and Bulus, 2000; Sivapullaiah and Baig, 2011) Other materials used as amending agent include secondary waste (Ganjian *et al.*, 2004) and natural clay-shredded tyre mixtures (Al-tabbaa and Aravinthan, 1998; Cokca and Yilmaz, 2004) One promising area of application of solid waste as alternative composite mineral liner material which at present lacks attention is in the incorporation of palm oil fuel ash (POFA) as additive material. POFA is a renewable bio-residue ash and is derived from palm oil milling industry. Judging from its physico-chemical properties and previous applications, POFA may be used as a potential cementitious and bio-sorbent additive in earthen sanitary landfill liner.

Large quantity of POFA waste generations are witnessed in rapidly developing countries like Malaysia, Indonesia, Thailand and Nigeria where varieties of oil palm trees species are being cultivated as cash crops (Subramaniam *et al.*, 2008; Yin *et al.*, 2008; Foo and Hameed, 2009; Patthanaissaranukool *et al.*, 2013; Ohimain and Izah, 2014) The powdery form of the ash as pulverized palm oil fuel ash (PPOFA) alone has been used as bio-sorbent in waste water treatment. The works of Zainudin *et al.* (2005) and Foo and Hameed (2009) are of particular interest in the area of study. Furthermore, the chemical compositions of POFA have shown that it may be used as supplementary cementitious material in concrete (Abdul Awal *et al.*, 2011; Ismail *et al*., 2011; Kroehong *et al.*, 2011; Jaturapitakkul *et al.*, 2011; Aldahdooh *et al.*, 2013;Yusuf *et al.*, 2014; Aldahdooh *et al.*, 2014) . Recently Amat *et al.* (2013) mixed raw POFA with gypsum and clay as binder to produce fire resistive panels used for internal partitions in buildings. As such, POFA may be incorporated into earthen landfill liner material for dual purposes of pozzolanic and cementitious material. The new composite material may be used as an alternative and sustainable landfill liner material.

However, extensive practical experiences with the application of industrial generated ash-wastes have confirmed the leaching of toxic heavy metals (Asl *et al.,* 2013; Çoruh *et al.,* 2013; Abdel Rahman *et al.,* 2013; Yao *et al.*, 2013; Houben *et al.,* 2013) Thus, the presence and leachability of toxic heavy metals from the use of POFA as earthen landfill liner material should not be ignored.

The uniqueness of this innovative research is that it has significantly contributed in moving to a new frontier the boundary of knowledge connected to the valuable use of POFA. As such, the research has changed the paradigms in the use of the agro-based waste to a new resource, by premixing kaolin with the PPOFA and use as an alternative composite landfill liner material. The research has critically examined the physical, chemical, and mechanical properties of each material component and the formulated composite kaolin-PPOFA liner material. The performance of the formulated mineral liner was examined in terms of its removal efficiency and sorption capacity of four selected heavy metal ions in single-elemental species (Zn^{2+}, Pb^{2+}, Cd^{2+}, and Cu^{2+}); the leachability of the selected heavy metals; and the hydraulic conductivity. Finally the transient contaminant transport performance of the aqueous solution formed with respective to each of the single-metal ions was examined.

1.2 Statement of the Problem

Recent studies have shown that municipal solid waste, industrial wastes, hospital wastes and other waste types pose major threat to the environment and globally constitute great challenges (Liamsanguan *et al.*, 2008; Zhen-shan *et al.*, 2009; Ngoc and Schnitzer, 2009; Karagiannidis *et al.,* 2010; Zaman, 2014; Farooqui, 2014; Aslani and Wong, 2014). For instance, in Malaysia about 28,500 tonnes of municipal solid waste (MSW) have been reported to have been directly disposed of into various landfills on daily bases (Agamuthu and Fauziah, 2011). The authors reported that most of the landfills in Malaysia contaminate the environment with the generated leachates as well as free emission of noxious landfill gases to surroundings. Similarly, a survey by Karagiannidis *et al.* (2010) revealed that on yearly bases in Greece, a significant part of the over 14,000 tonnes of infectious solid hospital waste generated are been mismanaged through dumping into household open-disposal sites and landfills after sterilization. In the recent years, China has been reported as the largest developing country in the world. The Landfill disposal technique has being the dominant disposal method for MSW generated in the country. Interestingly, as at 2006, China has 342 cost-effective municipal solid waste landfill sites which functionally accept heterogeneous wastes without requirement for separation (Chen *et al.,* 2010).

Due to its economic advantages and contributions toward the achievement of green and sustainable environment, sanitary landfilling of solid wastes continue to be the most economically viable and final solid waste disposal method (Chen *et al.*, 2010; Perkoulidis *et al*, 2010; Di Maria *et al.*, 2013; Yang *et al.*, 2013). However, waste containment in landfill sites enhances the concentrations of different dissolved and suspended pollutants as well as non-bio-degradable heavy metal ions leached from hydrated disposed wastes. The leachate formed is injurious to the public health and the environment at large. Landfill leachate as contaminated liquid effluent may percolate through liner material after the decomposition of deposited wastes. The liquid has been recognized as one of the most critical and detrimental issue in landfill operation (Ziyang *et al.*, 2009; Zhan *et al.,* 2013; Li *et al.,* 2013; Gallego *et al.,* 2014).

Despite the reliance of many communities on groundwater as main source of portable water and for culinary consumptions, the level of pervasiveness of its contamination and threat to the public health due to the varieties of toxic heavy metals ions is becoming unbearable (Chalermyanont *et al.,* 2009). Some of the common toxic heavy metals largely present in the leachate include, but not limited to lead (Pb), cadmium (Cd), copper (Cu), zinc (Zn), iron (Fe), nickel (Ni), and mercury (Hg). Consequently, many people have suffered great deal from carcinogenic and water borne ailment in connection with the consumption of leachate contaminated water (Zhang *et al.,* 2009; Nadaroglu *et al.*, 2010; Naser, 2013; Devic *et al.*, 2013).

More so, leachate contaminated groundwater has led to the imbalance in eco-system (Foo and Hameed, 2009). In addition, the liquid contaminant has contributed significantly to ozone layer depletion and greenhouse gas effect through the release of the heat trapping greenhouse gases (GHG) such as carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) (Oonk *et al.,* 2013; Ahmari and Zhang, 2013). Other non-environmentally friendly gaseous emissions as ammonia NH_4 and hydrofluorocarbons (HFCs) are also released to the surrounding environment. Accordingly, the installation of engineered and sustainable landfill liner is imperative since it constitutes one of the most important sub-system in the modern integrated and holistic solid waste management system (Edil, 2003; Demesouka *et al.,* 2013; Di Maria *et al.*, 2013).

The performance of engineered compacted clay liner has been evaluated hydraulically and most importantly on the basis of attenuation of various toxic chemical species (Fall *et al.,* 2009; Sunil *et al.*, 2009; Koutsopoulou *et al*., 2010; Hamdi and Srasra, 2013; Zhan *et al.,* 2013). Also, the sustainability in geo-liner material formulation will necessitate the introduction and use of locally available solid waste material as additional but relatively cheap and reactive cementitious material. Base on the foregoing, the research explored the potential of compacted kaolin modified with pre-determined dry mass of PPOFA (organic ash) as an alternative and sustainable landfill liner material.

The industrial kaolin used as the main landfill mineral liner was procured in Malaysia. Kaolin is one of the sizeable natural resources deposit in Malaysia (Ariffin *et al.,* 2008). It has been reported that Malaysia has some 112 million tonnes of kaolin reserves located in some of the states (Lee and Teoh, 1992). Thus, indicate high natural deposit coupled with active mining activity (Liew *et al.*, 2012; and Ismail *et al.*, 2013). It has also been reported that the surface chemistry of kaolinitic clay is less chemically reactive (Vizcayno *et al.* 2009). The soil may then be classified as unfavourable for use solely as earthen landfill liner. Despite this, existing literatures have shown that researches have focused on the use of kaolin as geo-liner (Srivastava *et al.*, 2005 and Mockovčiaková *et al.,* 2008). Thus, this research explored the advantage of the inherent chemical compositions of PPOFA and was used in enhancing the less reactive kaolin as alternative composite landfill liner material.

1.3 Aim and Objectives of the Research

The aim of this research is to experimentally study the potential of kaolin admixed with PPOFA as CCL. The specific objectives of the study are:

i. To establish the physical, chemical and mechanical characteristics of the industrial white kaolin, PPOFA and the formulated composite landfill liner material.
ii. To determine the attenuation efficiency and sorption capacity of four randomly selected single-element species (Pb, Cd, Zn, and Cu) sorbed onto the formulated mineral liner material via batch adsorption equilibrium test (BAET) and validate the experimental results with the Freundlich and Langmuir model and respective sorption isotherm curves.
iii. To determine the leachability of the industrial white kaolin, PPOFA and the formulated composite landfill liner material via batch leaching procedure (BLP).
iv. To determine the hydraulic performance of the compacted kaolin-PPOFA mineral liner material and compare with existing criteria for clay liner.
v. To determine the diffusion-retardation transport parameters governing the migration of the aqueous solutions of the four single-element species when permeated through the compacted column of the kaolin-PPOFA liner material.

1.4 Scope of the Research

The research was limited to laboratory based experiments, using the treated POFA as admixture to the kaolin. Both materials were obtained within Johor State of Malaysia. Initially the raw POFA was beneficiated by sieving and later subjected to two stages of milling process (i.e., hammer and ball milling). The industrial white kaolin was used as received with no further treatment. The simulated composite mineral liner material was formulated by introducing 375 g of the PPOFA to 2500 g dry mass of the industrial kaolin. Series of preliminary tests were conducted to establish the physical, chemical, and mechanical properties of the two basic component materials and their mixture as the composite liner material. The microstructural analyses conducted include the mass loss on ignition (*LOI*) analysis at predefined furnace temperature of 440 ± 25 °C and surface scanned morphology analysis using Energy Dispersive X-Ray Analyzer (EDX). Other microstructural analyses performed are the elemental and chemical compositions determined via Energy Dispersive X-Ray Fluorescence (EDXRF) spectrometer as well as the mineralogical composition which was determined via Brucker D8 Advanced X-Ray Diffractometer (XRD). The pH and the electrical conductance (EC) of the suspended solids of the three classes of materials were also determined.

The performance of the composite kaolin-PPOFA matrix as mineral liner was examined from the following criteria:

i. Metal sorption efficiency
ii. Adsorption capacity
iii. Metal leachability
iv. Hydraulic conductivity
v. Diffusion-retardation parameters.

Four different toxic heavy metal ion solutions which formed part of those commonly found in landfill leachates and are of significant interest to the environment (i.e., Zn, Pb, Cd and Cu), were prepared as single-metal solution. Subsequently, the respective solutions at varying concentrations were engaged in the determination of the sorption efficiency and capacity of the liner material using the BAET isotherm analysis. The initial concentration (C_o) of the four heavy metals used for the metal retention efficiency and isotherm sorption tests ranged from 10 mgL^{-1} to 120 mgL^{-1}. The presence and leachability of the four heavy metals in the kaolin, PPOFA, and the formulated liner material were examined through the BLP leaching test.

The falling head hydraulic conductivity test was conducted on series of compacted liner specimens prepared from the kaolin-PPOFA matrixes. For the test, eight specimens were prepared and compacted in respective transparent Perspex columns; where de-aired distilled (DI) water was used as the permeant. The completion of the hydraulic conductivity test was immediately followed by the column diffusion-retardation tests. The column test was performed with the influent concentration (C_{inf}) of each metal compound maintained at

0.0001M. The generated series of data from the test categories were analyzed and results obtained were compared with existing related literatures. In particular, performance of the formulated kaolin-PPOFA matrix as composite liner was as well compared with standard performance criteria for earthen liner material.

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