Jurnal
Teknologi

Full Paper

Attenuation Capacity of Soil Mixed with Palm Oil Fuel Ash (POFA) Liner for Treating Leachate

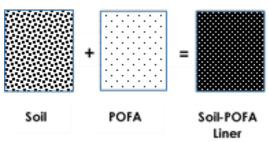
Nik Norsyahariati Nik Daud[a]*, Abubakar Sadiq Muhammed[a], Nadwatul Khodijah Misban[a], Wan Zuhairi Wan Yaacob[b]

[a]Department of Civil Engineering, Faculty of Engineering, Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia
[b]School of Environmental and Natural Resources Sciences, Faculty of Science and Technology, Universiti Kebangsaan Malaysia, 43600 Bangi, Selangor, Malaysia

Article history
Received
18 January 2016
Received in revised form
8 March 2016
Accepted
18 March 2016

*Corresponding author
niknor@upm.edu.my

Graphical abstract



Abstract

This paper presents the results of a study on the effectiveness of mixtures of granite residual soil with palm oil fuel ash (POFA) to attenuate leachate contaminants. Granite residual soil samples were mixed with 0 to 15% POFA. A short term filtration processes and hydraulic conductivity test were conducted simultaneously using a falling head apparatus with natural leachate as the permeant. The values of natural attenuation capacity of the compacted soil mixed with various percentage of POFA were determine by carrying out several water quality tests on the influent and effluent. The parameters measured were Total Suspended Solids (TSS), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD) values and some selected heavy metal (Chromium, Copper, Manganese, Lead and Zinc). The results showed the highest reduction in hydraulic conductivity (65.4%) was achieved by the compacted soil mixed with 10% POFA. The removal rate of all parameters studied except for copper increased with the increment of POFA content.

Keywords: Attenuation, leachate, residual soil, palm oil fuel ash

Abstrak

Manuskrip ini memperihalkan keputusan kajian keberkesanan campuran tanah baki granit dengan abu bahan bakar sawit (POFA) bagi melemahkan bahan pencemar larut lesap. Tanah baki granit dicampurkan dengan 0 kepada 15% POFA. Proses penurasan jangka pendek dan ujian hidraulik konduktiviti dijalankan dengan serentak menggunakan alat meter telap turus menurun dan air larut lesap digunakan sebagai larutan. Nilai Kapasiti pelemahan semulajadi oleh tanah campuran terpadat dengan peratusan POFA pelbagai ditentukan dengan menjalankan beberapa ujikaji kualiti air ke atas influen dan efluen. Parameter yang dikaji ialah *Total Suspended Solids* (TSS), *Chemical Oxygen Demand* (COD), *Biochemical Oxygen Demand* (BOD) dan kepekatan logam berat terpilih (*Chromium, Copper, Manganese*, *Lead* dan *Zinc*). Keputusan menunjukkan nilai penurunan tertinggi bagi hidraulik konduktiviti (65.4%) dicapai bagi tanah campuran terpadat10% POFA. Kadar penyingkiran bagi semua parameter yang dikaji kecuali *Copper* meningkat dengan peningkatan kandungan POFA.

Kata kunci: Pelemahan; bahan larut lesap; tanah baki; abu bahan bakar sawit

1.0 INTRODUCTION

The most desirable method for disposal of municipal solid waste is through landfill especially in developing country [1]. However, a substantial amount of leachate is produced as a result of rainfall or surface runoff percolating through the covers of these landfills. This leachate has high concentration of heavy metals and organic pollutants which serves as a source of contamination to the ground water body [2-4]. The properties of leachate depends on the amount water was seeping to the landfill, and on the chemical reactions between the solid and liquid phases [5].

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 [6]. Compacted clay soils or mixtures of soils with different additives (agricultural and industrial) are commonly used to achieve very low hydraulic conductivity barriers that prevent or reduce the infiltration of these contaminants [7- 9].

The selection and performance criteria for assessing the suitability of materials meant for hydraulic barriers in waste disposal facilities are low hydraulic conductivity, adequate shear strength and low potential for desiccation cracks and volumetric shrinkage [10, 11]. However, another fundamental design requirement and testing consideration is the compatibility between the barrier material and the fluid (leachate) to be contained. This implies the hydraulic barrier must maintain its low permeability and attenuate capacity after prolonged contact with the leachate [12, 13]. The main aim of these study is to evaluate the leachate compatibility and the attenuation capacity of granite residual soil mixed POFA based on short – term hydraulic conductivity test.

2.0 EXPERIMENTAL

2.1 Materials

The palm oil fuel ash (POFA) sample was obtained from a storage area of Southern Malay Oil Palm factory in Simpang Renggam, Johor, Malaysia (Figure 1a). The granite residual soil was collected from Hulu Langat, Selangor, Malaysia at coordinates of 3^0 7' 0'' N 101^0 49' 1" (Figure 1b).

(a) (b)

Figure 1 (a) The disposal practices of POFA around the factory in Johor and (b) the location of granite residual soil at Hulu Langat, Selangor

All samples were then transported to the soil laboratory for subsequent test. The soil contains 53.13% fines and the percentage of fines increase when POFA content increase in the soil. A liner material should have fine content of more than 20-30% [14]. The details about the location and sampling procedures of samples' collected can be found in Ref. [15, 16].

2.2 Methods

A compatibility study which is the interaction between the leachate and the barrier material was conducted based on the short – time hydraulic conductivity using leachate as the permeant. The test was carried out using a rigid wall permeameter under the falling head condition in accordance with procedure outlined in Ref. [17].

The soil – POFA mixture was compacted referred to the BS 1377-4: Compaction tests (Modified Proctor) and soaked for saturation. Tap water was used as the initial permeant for a period of ten days to establish a base line hydraulic conductivity, and then leachate was introduced for a period of 20 days. The change in hydraulic conductivity with the leachate and permeation time was studied.

Furthermore, in order to determine the natural attenuation capacity of the compacted soil, laboratory tests were carried out to determine the Total Suspended Solids (TSS), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD) and some selected heavy metals concentration by using and ICP – AES equipment (Perkin Elmer: Optima 3000XL).

3.0 RESULTS AND DISCUSSION

3.1 Leachate Compatibility

Compatibility of a liner material with leachate is a very important consideration in the design of waste containment facilities. The waste containment system must maintain its strength and regulatory hydraulic conductivity value after prolonged contact with leachate. Particles are highly susceptible to changes in moisture, physical and chemical interactions with the liquid to be contained [11, 18].

Figure 2 shows the trend in hydraulic conductivity values of granite residual soil and soil – POFA mixture over a period of thirty days.

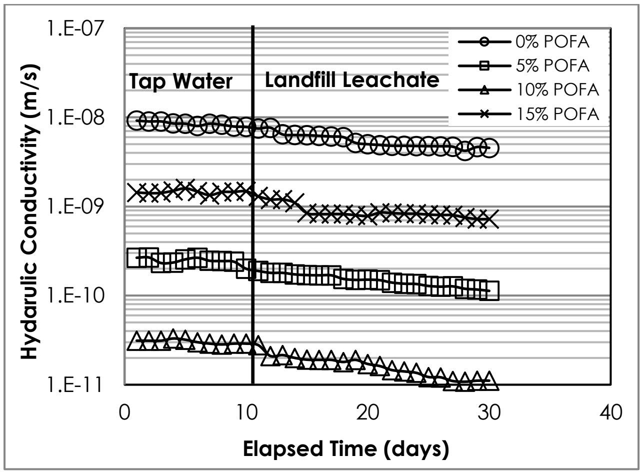


Figure 2 Variation behaviour of hydraulic conductivity of granite residual soil – POFA mixtures with time (permeated with water and landfill leachate)

For granite residual soil, the baseline hydraulic conductivity before introducing leachate as the permeant was 7.0×10^{-9} m/s, while the hydraulic conductivity value at the end of permeation period with leachate was 4.55×10^{-9} m/s. For soils containing 5, 10 and 15% POFA, the baseline hydraulic conductivities were 2.0×10^{-10}, 2.89×10^{-11} and 1.48×10^{-9} m/s, respectively. When leachate solution was introduced, the hydraulic conductivity at the end of the permeation period was 1.13×10^{-10}, 1.11×10^{-11} and 7.22×10^{-10} m/s for soils containing 5, 10, 15% POFA, respectively. The percentage reduction at the end of the permeation period for 0, 5, 10 and 15% POFA were 50.6, 57.5, 65.4 and 49.86%, respectively.

The trend in percentage reduction of hydraulic conductivity with addition of POFA can be due to the effect of increased fine content in the compacted soil – POFA mixture that reduced pores spaces and conductivity of leachate. Ref. [19] has shown that the hydraulic conductivity of laterite – fly ash mixture with municipal solid waste leachate decreases with increasing amount of fly ash due to increase in fines. Similarly, Ref. [20] observed the same phenomenon when foundry sand – bagasse ash mixtures was permeated with municipal solid waste leachate.

On the other hand, there was a slight decrease in hydraulic conductivity values with increased permeation period; these could be associated with biological clogging phenomena as a result of accumulation of suspended solids in the leachate. Biological clogging is a situation where pores with soils are filled up due to microbial activities; this phenomenon reduces the porosity and hydraulic conductivity of the soil [21]. These findings are similar to several previous studies [5, 22, 23]. They showed that a reduction of the hydraulic conductivity of compacted clay soil permeated with leachate occurs as a result of pore clogging. Furthermore, suspended solids and microorganism in leachate were gradually adsorbed on the surface of the soil, thereby blocking interconnected pores in the specimen and further reducing hydraulic conductivity. A similar phenomenon was observed by [5].

It can be concluded that the amount of suspended solids in landfill leachate plays an important role on the hydraulic conductivity of the barrier material by lowering the flow rate with time.

3.2 Attenuation Analyses

In order to check the natural attenuation capacity of the soil and soil – POFA mixtures, analyses on Total Suspended Solids (TSS), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD) and concentration of some heavy metals were carried out on both of the influent and effluent. Table 1 shows the values of water quality parameters and concentration of heavy metals of both the influent and effluent (0, 5, 10, and 15% POFA) in comparison to the Malaysian leachate discharge standards [24].

The pH values for both the influent and effluent ranged from 7.76 – 8.61 which was within the permissible limit given by the Environmental Quality Act 1974 (ACT 127) & subsidiary legislation [24]. The BOD value for the influent was 338mg/L, while the values for the effluent ranged from 109 – 276 mg/L. There was a reduction in BOD value with increasing POFA contents. The COD value obtained for the influent was 1335mg/L and it is also shown a similar behaviour as BOD values which is reducing with increasing POFA contents. Higher COD values were obtained by other studies [25-27]. They studied the general characteristics of various municipal solid waste leachate within Malaysia. The concentration of heavy metals was all below the standards values [24].

Table 1 Chemical and heavy metal concentration before and after treatment

Parameters	Raw Landfill leachate	Palm Oil Fuel Ash (POFA)				Std. [24]
		0%	5%	10%	15%	
pH	7.76	7.78	8.24	8.44	8.61	5.0 – 9.0
TSS (mg/l)	213	127	106	84	80	400
BOD_5(mg/l)	338	276	215	150	109	400
COD (mg/l)	1335	1061	950	810	750	1000
Chromium, Cr (mg/l)	0.167	0	0.001	0.005	0.002	2
Copper, Cu (mg/l)	0.031	0.024	0.024	0.026	0.026	10
Manganese, Mn (mg/l)	0.318	0.025	0.019	0.019	0.019	10
Lead, Pb (mg/l)	0.011	0.006	0.008	0.005	0.004	2
Zinc, Zn (mg/l)	0.326	0.075	0.068	0.053	0.016	10

Note: Total Suspended Solids (TSS), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD)

Figure 3 shows the removal rate of TSS, COD, BOD and heavy metals at different percentages of POFA. The initial TSS, BOD and COD values of the leachate were measured as 213, 338 and 1335mg/L, respectively. At the end of the permeation process, the highest removal rate for TSS, BOD and COD were 62.41%, 67.75% and 43.82% at 15% POFA content. The removal efficiency further buttresses the findings in Table 1.

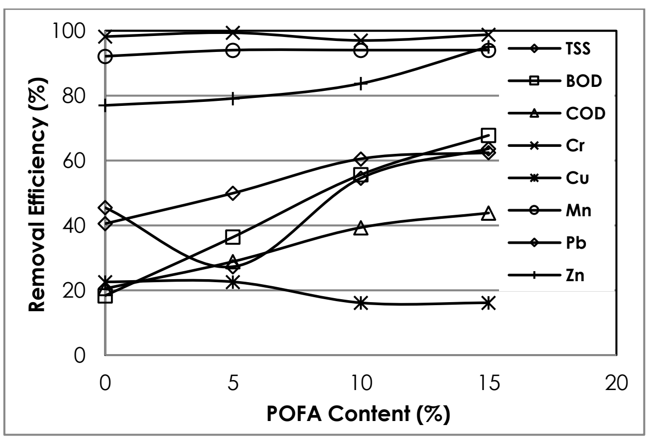


Figure 3 Variation removal rate of heavy metals at different percentages of POFA

On the other hand, heavy metals results showed that the removal rate of all heavy metals except for copper increased with the increment of POFA content. The greater attenuation capacity of the material was observed at 15% POFA as a result of higher POFA content which has greater specific surface area. Attenuation often occurs at the reactive surface of a particle, thus a material that has a relatively large specific surface area may make a relatively large contribution to heavy metal attenuation [29]. Furthermore, high specific surface area (SSA) also allows strong physical and chemical interactions with fluids and dissolved species, which subjected to electrostatic attraction, sorption or specific cation exchange reactions [29].

4.0 CONCLUSION

The study was carried out to evaluate the leachate compatibility and attenuation capacity of granite residual soil treated with palm oil fuel ash. A general decrease in hydraulic conductivity values at different percentages of POFA was observed, with the highest reduction rate of 65.4% was recorded at 10% POFA mixture. This could be as a result of suspended solids in the leachate which were absorbed on the surface of the soil there by reducing percolation with time. On the other hand the concentration of heavy metals in leachate was drastically reduced (except for Copper) when permeated through the compacted material with POFA. The greater attenuation capacity of the material was observed at 15% POFA as a result of higher POFA content. From the results, it can be concluded that the studied mixtures of soil-POFA have a potential to be used as liner in order to attenuate leachate at landfill site.

Acknowledgement

The financial support received from Fundamental Research Grant Scheme (FRGS No.: 03-01-13-1172FR) is gratefully acknowledged. Moreover the authors would like to express deep gratitude for technical support offered by the Geotechnical and Geological laboratory staff, Civil Engineering Department of Universiti Putra Malaysia.

References

[1] Ahsan, M. Alamgir, M. El-Sergany, M. Shams, S., Rowshon, M. K., and N. N. Daud. 2014. Assessment of Municipal Solid Waste Management System in a Developing Country. *Chinese Journal of Engineering*. Vol. 11. Retrieved from http://www.hindawi.com/journals/cje/aip/561935/

[2] Kjeldsen, P., Barlaz, M. A., Rooker, A. P., Baun, A., Ledin A. and 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.

[3] Chen, Y.-M. and Zhan, T. L. 2010. Environmental Geotechnics Related to Landfills of Municipal Solid Wastes. *Advances in Environmental Geotechnics* pp. 132–152. Springer. Retrieved from http://link.springer.com/chapter/10.1007/978-3-642-04460-1_8.

[4] Raghab, S. M., Abd El Meguid, A. M. and Hegazi, H. A. 2013. Treatment of Leachate from Municipal Solid Waste Landfill. *HBRC Journal*. 9(2): 187–192.

[5] Francisca, F. M. and Glatstein, D. A. 2010. Long Term Hydraulic Conductivity of Compacted Soils Permeated with Landfill Leachate. *Applied Clay Science*. 49(3): 187–193.

[6] Koivula, M. P., Kujala, K., Rönkkömäki, H. and 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.

[7] Eberemu, A. O., Amadi, A. A. and 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.

[8] Giridhar, V.P., Kumar, S. P. and Venkatasubbaiah, M. C. 2015. Experimental Studies on Clay, Bentonite and Leachate Mixer as Liner Material. Retrieved from http://www.ijirae.com/volumes/Vol2/iss1/44.JACE10088.pdf

[9] Rowe, R. K., Quigley, R. M., Brachman, R. W., Booker, J. R. and Brachman, R. 2004. Barrier Systems for Waste Disposal Facilities. Spon Press. Retrieved from http://www.cabdirect.org/abstracts/20043114094.html

[10] Daniel, D. E. and Benson, C. H. 1990. Water Content-Density Criteria for Compacted Soil Liners. *Journal of Geotechnical Engineering.* 116(12): 1811–1830.

[11] Frempong, E. M. and 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.

[12] Edil, T. B., Sandstrom, L. K. and Berthouex, P. M. 1992. Interaction of Inorganic Leachate with Compacted Pozzolanic Fly Ash. *Journal of Geotechnical Engineering*. 118(9): 1410–1430.

[13] Shackelford, D., Benson, C. H., Katsumi, T., Edil, T. B. and Lin, L. 2000. Evaluating the Hydraulic Conductivity Of GCLs Permeated with Non-Standard Liquids. *Geotextiles and Geomembranes.* 18(2): 133–161.

[14] Benson, C. Zhai, H. H. and Wang, X. 1994. Estimating Hydraulic Conductivity of Compacted Clay Liners. *Journal of Geotechnical Engineering*. *120*(2): 366–387.

[15] Nik Daud, N. N. and Mohammed, A. S. 2014. Material Characterization of Palm Oil Fuel Ash (POFA) Mixed with Granite Residual Soil. *Advanced Materials Research*. 955:2093-2097.

[16] Nik Daud, N. N. and Mohammed, A. S. 2014. Strength Assessment in the use of Granite Residual Soil Treated with Palm Oil Fuel Ash (POFA) as Hydraulic Barrier in Landfills. *Scottish Journal of Arts, Social Sciences and Scientific Studies*. 19 (II): 151 – 158. ISSN 2047-1278.

[17] BS1377 (5: 1990). British standard methods of test for soils for civil engineering purposes, Part 5: Compressibility, permeability and durability tests. British Standards Institution, London. (1990).

[18] Sivapullaiah, P. V. and Baig, M. 2011. Gypsum Treated Fly Ash as a Liner for Waste Disposal Facilities. *Waste Management*, 31(2), 359–369.

[19] Amadi. A. A. 2011. Hydraulic Conductivity Tests for Evaluating Compatibility of Lateritic Soil—Fly Ash Mixtures with Municipal Waste Leachate. *Geotechnical and Geological Engineering* 29(3), 259–265.

[20] George. M. 2012. Hydraulic and Contaminant Transport Performance of Compacted Bagasse Ash Treated Foundry Sand for Use in Waste Containment Facilities. Retrieved from http://196.220.64.8:8080/jspui/handle/123456789/3376

[21] Ivanov, V. and Chu, J. 2008. Applications of Microorganisms to Geotechnical Engineering for Bioclogging and Biocementation of Soil in Situ. *Reviews in Environmental Science and Bio/Technology*. 7 (2): 139–153.

[22] Li, J., Xue, Q., Wang P. and 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.

[23] Ozcoban, M. S., Cetinkaya, N., Celik, S. O., Demirkol, G. T., Cansiz, V. and Tufekci, N. 2013. Hydraulic Conductivity and Removal Rate of Compacted Clays Permeated with Landfill Leachate. *Desalination and Water Treatment*. 51(31-33): 6148–6157.

[24] EQA – Environmental Quality Act. 1989. Environmental Quality Act, Federal Subsidiary Legislation, Environmental Quality Act 1974, Malaysia.

[25] Aziz, H. A., Daud, Z., Adlan, M. N. and Hung, Y.-T. 2009. The use of Polyaluminium Chloride for Removing Colour, COD and Ammonia from Semi-Aerobic Leachate. *International Journal of Environmental Engineering.* 1(1): 20–35.

[26] Tatsi, A. A., Zouboulis, A. I., Matis, K. A. and Samaras, P. 2003. Coagulation–Flocculation Pretreatment of Sanitary Landfill Leachates. *Chemosphere*. 53(7): 737–744.

[27] Zin, M., Shaylinda, N., Abdul Aziz, H., Adlan, M. N. and Ariffin, A. 2012. Characterization of Leachate at Matang Landfill Site, Perak, Malaysia. *Academic Journal of Science*. 1(2): 317–322.

[28] Young, T. M. 2006. Natural Attenuation of Contaminants in Soils. *Vadose Zone Journal*. 5(3): 913–914.

[29] Oztoprak, S. and 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.