© APR 2026 | IRE Journals | Volume 9 Issue 10 | ISSN: 2456-8880
DOI: https://doi.org/10.64388/IREV9I10-1717139

Influence Of Coconut Shell Ash-Enhanced Filter Media in Electrokinetic Remediation (EKR) Treatment of Petroleum-Contaminated Soils

JOHN E. SANI[1], MUHAMMAD S. MOHAMMAD[2], ISHAKU M. VICTOR[3], GEORGE. MOSES[4]
[1,2,4]*Department of Civil Engineering, Nigerian Defence Academy, Kaduna*
[3]*Department of Civil Engineering, Federal university Wukari, Taraba*

Abstract- Petroleum contamination significantly degrades the physical, chemical, and geotechnical properties of soils in oil-producing regions. Electrokinetic remediation (EKR) has emerged as a promising technology for treating low-permeability soils, but its efficiency is strongly influenced by the nature of the electrode filter media. This study investigates the performance of coconut shell ash (CSA) as an enhanced filter medium in the EKR treatment of crude-oil-contaminated soil (COCS). Laboratory EKR cells were operated for a fixed duration using ethanol and acetone cosolvents to facilitate hydrocarbon mobility. Results show that CSA significantly improved contaminant migration toward the cathode and increased total petroleum hydrocarbon (TPH) removal efficiency. The EKR system with CSA achieved a maximum TPH removal of approximately 74.6%, outperforming acetone-assisted systems (≈67.8%). Post-treatment soils also exhibited improvements in geotechnical properties, including higher dry density and reduced plasticity index. These findings demonstrate that CSA is a low-cost, environmentally friendly additive that enhances the efficiency of EKR systems. The study provides insight into sustainable waste-to-resource applications for tropical engineering practice.

Keywords: Electrokinetic Remediation, Petroleum-Contaminated Soil, Coconut Shell Ash (CSA), Hydrocarbon Removal, Cosolvent Flushing, Geotechnical Restoration, Sustainable Soil Treatment.

I. INTRODUCTION

The performance characteristics of soil in engineering applications including compaction, strength, permeability, shrinkage, and compressibility. They play a vital role in determining the suitability of soil for various engineering applications, as highlighted by Nigerian General Specification for Road and Bridges (NGSRB) in 2016 Road structure failures can be traced back to multiple factors, including substandard construction materials Ademola (2017), flawed design and construction practices Young (2021), excessive loading, inadequate drainage, and construction defects, which can lead to structural weaknesses and compromise the safety and longevity of infrastructure projects.

Engineering properties of soils are very important in deciding the suitability of soils for structural uses. These properties of soil do not always remain the same throughout the design life of roads. They can vary as a result of capillarity action, flooding, seismic loads, frost action, and exposure to various contaminants Akinwunmi (2014). Soils that experience variations due to one or some of these reasons are considered not durable for road use Ibrahim (2011). One of the contaminants which have led to the abandonment of projects, change in projects scope or great increase in projects cost is oil in the form of hydrocarbon, which can be crude oil or any of its fractions Rahman (2010).

The variations in the engineering properties of soils due to the presence of oil have been reported in many researches. Oyediran (2022) maintained that the lubricating effect of crude oil led to the decrease in the optimum moisture content (OMC) and an increase in the maximum dry density (MDD) of crude oil contaminated alluvial soil. An increase in the compressibility and a decrease in permeability of different type of soil was reported by Al-Qaisee, Mohammad & Mahdi, (2020) when contaminated with black oil. The unconfined compressive strength increases with up to 10% oil content before decreasing at higher percentages. The in-situ condition of the contaminated soil was recommended for use under the foundation as long as it is isolated from living creatures. Remediation or stabilization was recommended due to a reported decrease in compaction parameters (OMC & MDD), California Bearing Ratio (CBR) and permeability of crude oil contaminated lateritic soil with increasing oil content (Akinwunmi et al., 2014). Iloeje &Aniago (2016) have reported a sinusoidal trend in the permeability of an A-6 (CL) soil with crude oil, an initial decrease in permeability from 0% to 2% crude oil content is followed by subsequent no proportional increase. This trend can affect the natural groundwater recharge of the soil and soil aeration through bioremediation can be used to remedy the defect. Negative effects of using crude oil contaminated soil for roads and building construction is further stressed when Suleiman, (2020) observed a decrease in the MDD, CBR and cohesion of clay soil. These effects are further strengthened by the decrease in shear strength and an increase in compressibility of oil contaminated clay soil obtained by Karthikeyan & Ramachandran, (2020).

While EKR's successful extraction of pollutants from soil is a relatively new technology with promising characteristics, significant research gaps remain. These includes determining the suitability of electrodes/electrolytes for different local soil types, the effect of voltage and current variability on the EKR process in light of local soil conditions, the effect of the EKR technique on the engineering properties of soil, the physicochemical characteristics of remediated soil, and putting it to engineering uses that can withstand their design life. Answers to these and other concerns are critical for increasing the efficiency of EKR, expanding its applicability, and adapting it to Nigerian conditions. Mining activities inject large volume of waste into the soil, as an open and crucial system in the environment, the soil is forced to accept waste and pollutants and, thus poses a huge threat to humans and the environment with acid mine drainage and tailings can contaminate nearby water sources Aderx (2019).

Coconut shell (CS) is an agricultural solid-waste material that has been raising environmental concerns to people living around the production site. The poor management, utilization, and proper disposal of agricultural wastes caused environmental menace which affects the health status of the dwellers. Notwithstanding, a lot of benefits had been exploited by several researchers varying from particulate for structural or construction additives, powder reinforcement in polymer and metal matrix composites, water purification, and energy generation. Coconut shell ash (CSA) has been reported to have produced the highest activated carbon among the agro waste materials Suleiman (2020). Coconut plant has lots of useful waste materials such as fronds, husk as well as shell.

The use of activated coconut ash for soil remediation is an environmentally friendly remediation procedure and offers lots of successes in recovering and restoring the quality of contaminated soil. CSA is an effective agent for the treatment of contaminated soils because it effectively adsorbs heavy metals and decreases bioavailability and toxin-induced stress to plants and microorganisms Mackie (2015). This study evaluates the influence of CSA-enhanced filter media on TPH removal efficiency in petroleum-contaminated soils.

II. MATERIALS AND METHODS

2.1 Soil Sample Collection and Preparation

Soil samples were obtained from a crude-oil-impacted site and homogenized in the laboratory. The natural soil was air-dried, pulverized, and sieved through a 2 mm mesh. Contamination was simulated by thoroughly mixing the soil with a known volume of crude oil to achieve controlled TPH levels.

2.2 Coconut Shell Ash (CSA)

Coconut shells were cleaned, sun-dried, and burnt in a controlled furnace at 650–700 °C to obtain fine ash. The ash was sieved through a 1 mm sieve and chemically characterized to ensure its suitability as a filter medium. CSA was placed in the electrode chambers as a reactive barrier.

2.3 Electrokinetic Remediation Cell Setup

With little modification to the electrokinetic remediation setup by Yu, (2019). The solar powered active coconut shell ash filter media enhanced EKR setup used in this study The DC supply is used to supply constant 30 V and maximum of 5 A through graphite electrodes (two at both ends) to the contaminated soil in the setup to achieve 1 V DC/cm across the setup. The setup was maintained under such condition until no effluent was observed from the cathode valve or constant current was observed.

For the purpose of classification, checking compliance and determining the degree of improvement obtained in the engineering properties of the enhanced EKR crude oil contaminated soil, the following laboratory tests were to be carried out on both the COCS and the EKR soils in accordance with (BS 1377, 1990). Methods of Tests for Soil for Civil Engineering Purposes as recommended in Meshari (2021) Tests to be Carried Out.

Plate I: EKR setup during remediation

2.4 Use of Cosolvents
Two cosolvents were introduced to enhance hydrocarbon solubility and mobility: Ethanol and Acetone. These were periodically added to the anode reservoir during operation.

2.5 Monitoring Parameters
Soil samples was mixed properly with representative crude oil. The samples should simulate real-world conditions measured crude oil concentrations using appropriate analytical methods such as gas chromatography or spectrophotometry. Design and set up the electrokinetic cell for each experimental condition. A proper seal was ensured to prevent contamination and electrolyte leakage. Filter Media Configuration: activated coconut shell ash was placed as filter media within the electrokinetic cell. Then voltage gradient was applied across the soil samples using the electrokinetic setup. Current and voltage was to ensure the proper operation of the electrokinetic system. Run experiments for different treatment durations and voltage gradients to assess their effects on remediation efficiency. The movement of crude oil and the changes in soil properties during electrokinetic remediation was monitored. The performance of activated coconut shell ash in capturing and retaining crude oil, soil pH and changes in soil properties (e.g., texture, moisture content) before and after remediation was analyzed. Collected samples from the anode and cathode reservoirs for analysis were Recorded with data related to crude oil concentrations, pH, and soil properties at various time intervals and treatment conditions. Finally, the data was analyzed statistically to assess the impact of activated coconut shell ash on crude oil removal efficiency in electrokinetic remediation. Quality control measures was implemented to ensure the reliability of results, including duplicate experiments and instrument calibration. Adhere to safety protocols for handling crude oil and working with electrical equipment

Plate II: Setting up process of the EKR

During the remediation process, the following parameters were monitored:

- Voltage and current variation
- Electrode chamber pH
- Temperature
- Electroosmotic flow
- TPH concentration at various points
- Soil geotechnical properties (post-treatment)

2.6 Analytical Methods
TPH concentration was quantified using standard solvent extraction and UV-spectrophotometry procedures. Geotechnical tests included:

(i) Atterberg limits
(ii) Compaction test (MDD and OMC)
(iii) Shear strength
(iv) Permeability

2.7 Experimental Duration
The experiments were conducted for a fixed period (e.g., 5–7 days) depending on stabilization of electrokinetic processes.

III. RESULTS AND DISCUSSION

3.1 Effect of CSA on TPH Removal Efficiency
From the result presented in table 1 and figure 1 it shows that remediation using activated coconut shell ash (ACSA) at 0.5cm has higher removal efficiency of 71.47% compare to other thickness of the ACSA using 1m of the solution and distilled water as the purging solution. Similar trend was obtained by (Adebayo et al., 2023) activated ash as filter media enhancements showed higher removal efficiency, for

COCS than un-activated at 1cm and 1.5cm. The effect of varying thickness remains unexplored a similar trend were also obtained by (Haruna et al., 2024) testing filter media thickness which shows highest lead removal efficiency of 92.97% occurred at 2.0cm while the lowest at 0.5cm of 91.15%. But here ACSA its higher at 0.5cm this may be due to at 0.5cm of ACSA thickness might provide a larger surface area to volume ratio enhancing adsorption capacity because thinner layers can facilitate raster diffusion of contaminants allowing for more efficient removal. ACSA increases the solubility of hydrocarbons making it easier to remove them from the soil, it also improves electro osmotic flow which helps to transport the contaminant towards the electrode, increase ionic strength of the solution, and reduce the attraction between soil particles and the contaminant. Jamshid & Khodadadi (2017).

The ACSA filter under different thickness, due to its amorphous structure can be seen to enhance the removal of the mobilized crude oil from the soil by adsorption to its pores. a similar result was reported by (Romina et al., 2021) on reactive filter media (RFM), in changing the amount of RFM it shows an impact on the efficiency of heavy metals removal 51.6% to 72.1% under 14 days treatment duration. It also shows high removal efficiency at 2cm thickness of ACSA of 65.95% and low efficiency at 1cm and 1.5cm thickness, this may be due to its low stability of complexes under acidic condition making it difficult to prevent the formation of secondary minerals. This low efficiency may be due to low surface area reducing its ability to absorb hydrocarbons and limited chemical activity. This supports (Yu, 2019) where the chemical activation on the ACSA is emphasized to play a role in contaminants adsorption and increasing the surface activity of the filter thereby increasing the rate of contaminants removal.

Table 1. Summary of ACSA Filter Media with different thickness Enhanced EKR of COCS

	0.5cm	1cm	1.5cm	2.0cm
Initial TPH (mg/kg)	10,865	10,865	10,865	10,865
Duration (days)	18	17	20	14
TPH after remediation (mg/kg)	3100	3900	3900	3700
Remediation Efficiency (%)	71.46801657	64.10492	64.10492	65.9457

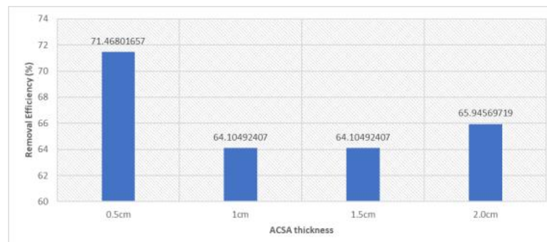

Fig 1. Removal efficiency of the EKR soil ACSA with different thickness

3.2 Influence on Electrokinetic Transport Mechanisms

CSA improved the stability of electroosmotic flow and reduced pH fluctuations at the electrodes. The ash acted as a buffer and minimized electrode passivation, thereby enhancing electric current uniformity throughout the soil. This enabled greater contaminant mobility and minimized soil resistance.

3.3 pH Variation Across the Soil Profile

Variation potential under different pH simulate the experimental conditions for the soil-pollutant-soil solution interaction, the pH value starts from 6.5, 7.3, 8.7 and 9.7 which end at 10.8, 9.8, 8.7 and 8.7 for remediation using activated coconut shell ash with different thickness as filter media as shown in fig 2. Since the pH at the interface changes the potential value of the pH can induce the conditions for pollutant desorption. The pH variation at the interface also depends on the buffer capacity of the soil sample as observed. If the buffer capacity is high, the soil will keep the same interfacial conditions regardless the fluid pH. Mobility was detected due to change in the pH value, similar trend were obtained by

(Adebayo et al., 2023; Moses et al., 2020). The distribution species diagram revealed that cationic species of contaminant migration. Under this consideration it should be assumed that lower pH values will promote cationic Yuan (2017). From the result remediation using activated coconut shell ash under different thickness as filter media has lower value of pH due to the transport of ion across the soil and the current density and electric field strength.

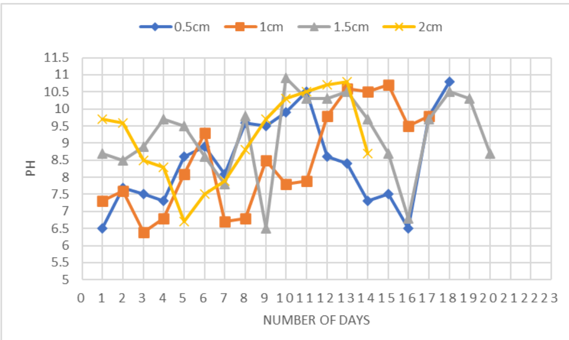

Fig. 2 variation of pH in EKR with ACSA with different thickness

3.4 Changes in Geotechnical Properties Post-Treatment

Remediated soils demonstrated improvement:

3.4.1 Plasticity index

The greater the plasticity index, the greater the compressibility of soil. The plasticity index of the COCS was 29.42 which later reduce to 16.07, 19.11, 17.78 and 17.29 using 0.5cm, 1cm, 1.5cm and 2cm thickness of ACSA as filer media respectively (See Figure 3). Remediation shows a decrease in the PI value. PI within 7%- 17% are medium plastic and are very cohesive. It is generally a safe area for construction, the Pi of the remediated soil using ACSA at 0.5 to 2.0cm shows medium value which may not respond to swelling conditions, and lower than the range would render the soil low in plasticity and non-cohesive. Which is not safe for construction. This trend in low plasticity index for the remediated soil using activated coconut shell ash is seen to follow similar trend reported by (Adebayo et al., 2023; Oyediran & Enya, 2020; Salimnezhad, 2021). The plasticity index of the COCS, and remediated soil

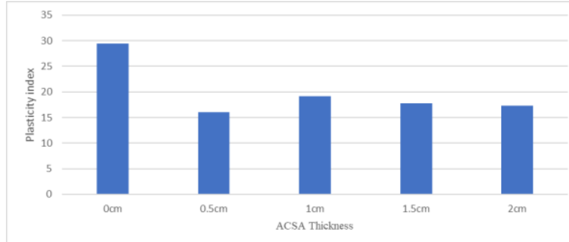

Fig. 3: variation of plasticity index for COCS, ACCSA under different thickness

3.4.2 Maximum Dry Density

Compaction test was conducted to attain the result of the maximum dry density of the soil samples using both BSL, WAS and BSH Compactive effort was determined to be 1.66mg/m3 to ,1.69mg/m3 , 1.75mg/m3to 1.80mg/m3 and 1.83mg/m3 to 1.89mg/m3 for COCS and 0.5cm, 1cm, 1.5cm and 2cm thickness of ACSA as filer media respectively. There was a general increase in maximum dry density for all the three energy levels as shown in Figure.4 which shows better particle parking and reduces voids (Moses et al., 2012; Oriola et al., 2010) There was an increase in MDD at 0.5cm thickness of ACSA and later reduce at 1.0cm and 1.5cm with the highest MDD at 0.5cm and 2.0cm thickness for both BSL and BSH effort but increases at 1cm thickness under WAS effort..

The MDD generally increased when remediated using 0.5cm, 1cm, 1.5cm and 2cm thickness of ACSA as filer media. This could probably be as a result of the higher specific gravity value of 2.70 Osinubi & Ijimdiya, (2008). Greater maximum density gives good compressive strength to the soil material. (Moses, 2019). These trends are similar to those reported by (Adebayo et al., 2023; Zulfahmi, 2010; Akinwunmi, 2014; Nwachukwu, 2020; Suleiman, 2020; & Salimnezhad, 2021). From the result the three-energy level have influence on the soil maximum dry density (Moses et al., 2012). The maximum dry density of the soil samples are shown in the graphical representation in fig 4.

DOI: https://doi.org/10.64388/IREV9I10-1717139

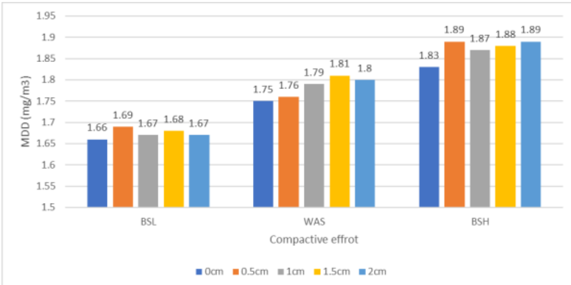

Fig 4: variations of MDD for COCS, ACCSA under different thickness

Higher maximum dry density (MDD)

3.4.3 Optimum Moisture Content

The optimum moisture content of the COCS and remediated soil using ACCSA under different thickness at BSL WAS and BSH Compactive effort are shown in figure 5. Generally, there was a decrease in the optimum moisture content. From 14.46% to 13.19%, 13.14% to 12.14 and 11.60, to 10.84% for the COCS and ACCSA under different thickness using the three Compactive effort respectively. (OMC) decreased with ACCSA under different for BSL, WAS and BSH. This was due to the increase in soil temperature, decreased soil moisture and lower ion charge in fines content resulting from the inclusion higher voltage and higher current level with larger surface area that required more water to react, higher compaction effort can achieve optimal density at lower moisture and lower clay content (Moses et al., 2012). The lower OMC for the filter media enhanced EKR can be seen to be due to the reduced crude oil content of the soils which reduces the thickness of the adsorbed water and relatively increases the particle to particle contact of the soil grains, the addition of water ensures the lubrication of the particles and closer packing of the soil grains. This similar trend was also obtained by (Adebayo et al., 2023; Nwachukwu & Onyechere, 2020)

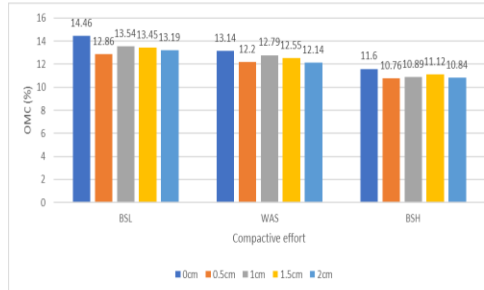

Fig 5: variation of OMC for COCS, ACCSA under different thickness

3.4.4 Unconfined Compressive Strength

The results of Unconfined Compressive Strength (UCS) values after remediation of the COCS, by using activated coconut shell ash under different thickness to enhance filtration in COCS remediation with BSL, WAS and BSH Compactive effort as show in Fig 6.

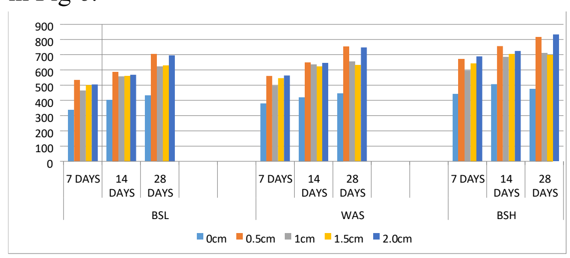

Fig 6: Variation curing days and the three compactive efforts for UCS (COCS and ACCSA under different thickness)

From the result using BSL compactive effort shows an increase in the curing days from 7,14 and 28 days the UCS value for 7,14 and 28 days at 0.5cm thickness of ACSA has the highest strength 534.51 kN/m2, 587.8 kN/m2 and 703.22 kN/m2 followed by 2.0cm for 14 and 28 days curing period at 568.34 kN/m2 and 695.54 kN/m2 respectively. These was also due to better particle arrangement of the BSL compactive effort (Moses et al., 2012) Although, there were slight drops in the UCS values at 1cm and 1.5cm for BSL compactive effort, the results indicate that ACSA under different thickness has long time strength improving capability Akinmade (2008). Comparing with WAS compactive effort it is higher at 2.0cm thickness of ACSA with 563.7 kN/m2 and 747.32 kN/m2 under 7 days and 28 days curing period respectively only 14 days curing to be at 0.5cm thickness of ACSA. This shows similar trend obtain by (Moses et al., 2012) of increase similar to that of the 7days curing period. Lastly the higher energy level which is BSH is having the highest strength recorded with increase in number of curing period from 7 to 28 days period, showing high strength of 816.4kN/m2 at 0.5cm thickness of ACSA. This trend is similar to what is obtained by (Oriola et al., 2010). Improve in soil strength can increase the soil density or the use of stabilizers like cement or lime (Moses et al., 2012) to improve strength.

These improvements indicate the soil became more stable and suitable for engineering applications, including possible use as subgrade material in road construction.

3.5 Environmental and Economic Significance

CSA is abundant, renewable, and cost-effective using agro-waste helps promote sustainable engineering Improved EKR efficiency demonstrates potential for large-scale deployment. The combined effect of CSA and ethanol makes the process more viable for field conditions in petroleum-polluted regions.

IV. CONCLUSION

Based on the results obtained the following conclusions can be made

The result shows that remediation using activated coconut shell ash (ACSA) at 0.5cm has higher removal efficiency of 71.47% compare to other thickness of the ACSA using 1m of the solution and distilled water as the purging solution.

Based on index properties result, the COCS soil belongs A-7-6 while the ACSA at 0.5cm, 1cm, 1.5cm and 2cm thickness belongs to A-6 AASHTO Soil Classification System, which indicate an improvement in the soil properties. The specific gravity increased using Activated coconut shell ash using different thickness. The plasticity index also decreased then after the electrokinetic remediation. However, the remediated soil using ACCSA values of plasticity indices met the 7-17 % medium level for safe foundation but did not meet the 12% plasticity index specified by clause 6201 of the Nigerian General Specifications (1997) for sub base materials. The sieve analysis shows a well graded modification after remediation from 43.05% passing no.200 BS Sieve to 40.95%, 41.4%, 42.15% and 40.1% of ACSA under different thickness. Electro kinetic remediation of the COCS using the ACSA under different thickness showed a general decrease in the OMC and increase in MDD using BSL, WAS and BSH Compactive effort.

The UCS result under 7 days curing 0.5cm thickness is having the highest strength of 534.51 kN/m2, 560.27 kN/m2 and 670.66 kN/m2 using BSL, WAS and BSH effort respectively. All the Compactive efforts recorded increased in the UCS values for the ACSA under different thickness 14 days curing All the Compactive efforts recorded increased in the UCS values for the ACSA under different thickness from 403.1kN/m2 to 725.16kN/m2 under the three Compactive effort. 0.5cm and 2.0cm ACSA Thickness respectively. while 28 days curing period for BSL compactive effort increased from 431.5kN/m2 to 703.22kN/m2 ,446.2kN/m2 to 754.3 kN/m2 and at 0.5cm thickness for BSL and WAS energy respectively. The peak strength value was at BSH compactive effort at 830.95 kN/m2 at 2.0cmthickness of ACSA remediation The UCS result shows that remediated soil using ACSA at 0.5cm and 2.0cm thickness for all the Compactive effort has the highest strength value The CBR value increased when remediated with ACSA using different thickness. The unsoaked CBR gave a peak value of 33.6% at 2cm ACSA thickness under BSH Compactive effort from a value of 19.4% for the EKR COCS meets the 15% recommended for subgrade material as specified. While the soaked CBR shows a peak value of 11.04% at 1cm ACSA thickness under BSH effort did not meet the 15% recommended for sub-grade material by the Nigerian General Specifications (2016), but has met the requirement for lightly traffic road.

This study demonstrates that coconut shell ash significantly enhances the efficiency of electrokinetic remediation of petroleum-contaminated soils. The CSA-enhanced system achieved higher TPH removal, improved electroosmotic flow, stabilized pH levels, and produced soils with better engineering properties. Ethanol proved to be a more effective cosolvent compared to acetone.

CSA is a low-cost, readily available, and eco-friendly material, making it suitable for integration into fullscale remediation strategies, especially in developing countries with high levels of petroleum pollution. The findings contribute to the advancement of sustainable soil remediation technologies.

REFERENCES

[1] Adebayo K., Moses G., Sani J. E., Haruna B. I and Balarabe F. (2023). Filter media enhanced electrokinetic remediated crude oil contaminated soil for use in road construction: a comparison of charcoal and active carbon. Nigerian Journal of Technology, vol. 42, No. 2.

[2] Ademola, O. (2017) "Engineering evaluation of lateritic soils of failed highway sections in Southwestern Nigeria" *Geosciences Research,2*(3), ,https://dx.doi.org/10.22606/gr.2017.23006

[3] Aderx, A. (2019). Environmental impacts of mining activities on soil and groundwater systems. Journal of Environmental Engineering, 25(3), 112–124

[4] Akinwunmi, I. I., Diwa, D., and Obianigwe, N. (2014) "Effects of crude oil contamination on index properties, strength and permeability of lateritic clay", *International Journal of applied Science and Engineering Research*, *3*(4), , 816-824.

[5] Akinwunmi, I. I., Diwa, D., Obianigwe, N. (2014). Effects of crude oil contamination on index properties, strength and permeability of lateritic clay. International Journal of applied Science and Engineering Research, 3(4), 816-824.

[6] Al-Qaisee, G. S., Mohammed, A. R., and Mahdi. E. M. (2020)"Black oil leakage influence on the physical and engineering properties of Few soil", *Journal of Southwest Jiaotong*

[7] Haruna B. I and Balarabe F. (2024). Filter media enhanced electrokinetic remediated crude oil contaminated soil for use in road construction: using active carbon. Nigerian journal of Technology, vol. 42, No. 2.

[8] Ibrahim, M. A., Maofaq, A. A., and Iloeje A. F. and Aniago V. (2016). Effect of crude oil on Permeability properties of the soil. International Journal of Trend in Scientific Research and Development, Vol. 1(1). ISSN: 2456 – 6470

[9] Iloeje, A. F., and Aniago V. 2016 "Effect of crude oil on permeability properties of the soil", *International Journal of Trend in Scientific Research and Development*, *1*(1), , 39-43.

[10] Jamshed, F. B., and Khodadadi G. (2017) *International Research Journal of Engineering and Technology (IRJET),4*(11), 2017, 17181720

[11] Karthikeyan, S. and Ramachandran, A. 2016 "Physical and engineering properties of oil contaminated clay soil", *International Journal of Engineering Research & Technology*

[12] Mackie, C. N., Yong, R. N. Gibbs, B. F. (2015). Surfactant-enhanced remediation of contaminated soil: a review. Engineering Geology, 60, 371-380.

[13] Meshari, S. A. (2021). Determination of total petroleum hydrocarbons (TPHs) in weathered oil contaminated soil. Environmental Engineering Research, 27(5), DOI: https://doi.org/10.4491/eer.2021.324

[14] Moses, G., Etim, R. K., Sani, J. E., Bobai, Y. S. (2019). Geotechnical properties of crude oil incinerated lateritic soil for use in roadwork. FUW Trends in Science & Technology Journal, 4(1), 069-074.

[15] Moses, G., Saminu, A,. 2012 cement kiln Dust stabilization of compacted black cotton soil EJGE Journal vol. 17 (2012) Bund F

[16] Moses, G., Saminu, A,. Oriola F.O,. 2012 "Influence of compactive effort on compacted foundary sand treated with cement Klin dust'' international journal IISTE vol 2, No. 5 (2012)

[17] Nigerian Standards for Soil Remediation (2022). NESREA/Soil/Guidelines/05.

[18] Nwachukwu, A. N., Okoro, B. C., Osuagwu, J. C., Nwakwasi, N. L., and Onyechere, I. C. "Index and compaction properties of oil contaminated clay soils in Niger - Delta region of Nigeria", *Saudi Journal of Engineering and Technology*, *5*(2), 2020, 81-85.

[19] Oyediran, I. A., and Enya, N. I. 2020 "Variations in geotechnical characteristics of some crude oil contaminated soils", *Global Journal of Geological Sciences*, *18*, , 75-88.

[20] Oyediran, I. A., Enya, N. I. (2021). Crude oil effects on some engineering properties of sandy alluvial soil. International Journal of Mining and Geo-Engineering, 55(1), 7-10.

[21] Oyelami, W. (2022) Integrating electrokinetic and bioremediation process for treating oil contaminated low permeability soil", *E3S Web of Conferences*, *31*, 2018, 03005

[22] Oriola, F.O,. Moses, G,. (2010) ''groundnut shell ash stabilization of black cotton soil EJGE Journal vol 15 (2010), Bund, E.P.

[23] Osinubi, K. J., & Ijimdiya, T. S. (2008). *Influence of crude oil contamination on the geotechnical properties of lateritic soil*. Journal of Engineering Research, 13(2), 45–52.

[24] Romina, S. and Sylvert, P. 2021 "Oil contamination on geotechnical properties of clayey soil", *International Journal of Engineering Research & Technology ,3*(29), 2021, 3-18.

[25] Salimnezhad, A., Soltani-Jigheh, H., and Soorki, A. A. 2021 "Effects of oil contamination and bioremediation on geotechnical properties of highly plastic clayey soil", *Journal of Rock Mechanics and Geotechnical Engineering*, *13*, 2021, 653-670.

[26] Suleiman, A., Salim, I. M., Timothy, A. A., and Abdulrahman, H., Yusuf, B. A., Sadi, I. H. 2020 "Effect of crude oil spillage on engineering properties of tropical residual soil", *IOP Conference Series Earth and Environmental*

[27] Young, E. O., Alexander, O. S., Anulf, S., and Johnbosco, N. 2021"Geological and geotechnical investigation of road failures in Nigeria: a case study of parts of Imo-Abia States, Southeastern Nigeria", *Engineering Research Journal,1*(4), 2021, 1-15.

[28] Yu. 2019 "electrokinetic remediation for treating a heavy metals (iron) contaminated soil", *Separation Science and Technology*, *8*(7), 2019, 457-675.

[29] Yuan, S. H., Wan, J. Z., and Lu, X. H. 2010 "Hydroxypropyl-cyclodextrin enhanced electrokinetic remediation of sediment contaminated with HCB and heavy metals", *Journal of Hazardous Materials*, *176*, 2010, 306-312

[30] Zulfahmi, A. R., Umar, H., Mohammad, R. T., Norsheila, S. I., and Noorulakma, A. 2010"Influence of oil contamination on geotechnical properties of basaltic residual soil", *American Journal of Applied Sciences,7*(7), 2010, 954-961.