



CHEMICAL IMPROVED OIL RECOVERY USING CERTAIN AGRO-WASTE AS NATURAL ALKALI AGENTS WITH PHYTOCHEMICAL CHARACTERIZATION

Mr. Akshay Ganpat Tajane¹, Prof. Yogeshkumar R. Falak², Mr. Sachin Jagannath Chede³

Article History: Received: 12.12.2022

Revised: 29.01.2023

Accepted: 15.03.2023

Abstract

According to studies, the application of alkaline during surfactant flooding causes a very low interfacial tension between the oleic and aqueous phases, a change in the rock's wetness, emulsification and coalescence, and a decrease in the amount of surfactant that is adsorbed. These alkaline chemicals are poisonous and unfriendly to the environment, nevertheless. A fresh option is the creation of natural-based oil recovery agents. By analysing their mineral and phytochemical makeup, the potential of *Brophyllum pinnatum* (never die leaf), *Elaeis guineensis* ash (palm bunch ash), *Musa paradisiaca* ash (plantain peel ash), and potash as natural alkaline sources for usage as chemical enhanced oil recovery agent was determined. Using atomic absorption spectroscopy (AAS), Fourier-transform infrared spectroscopy (FTIR), and gas chromatography (GC-FID), the materials' mineral and phytochemical contents were identified. The suitability of these materials as recovery agents was assessed using quantitative investigation of their elemental and biomolecule content. The findings indicated that *Brophyllum pinnatum* has a high level of organic matter as well as several phytochemicals in different amounts, including flavonoids, alkaloids, and saponin. The results show that these minerals are ideal candidates for alkaline flooding, with potash having the highest pH value of 11.1 at 1% conc. pH is a key factor in alkaline flooding. Divalent ions (calcium and magnesium), which are frequently present on rock surfaces or in the formation brine, were detected in greater concentrations in potash, with values of 7.89 ppm and 4.50 ppm, respectively. Potash would be less prone to issues with phase incompatibility and scale development during oil production as a result. *Elaeis guineensis* ash and potash had greater concentrations of monovalent ions, potassium, and sodium, respectively. Inorganic carbonates and potassium hydroxide were present in all of the materials except *Brophyllum pinnatum*, further demonstrating their suitability as excellent alkaline agents for chemical flooding. Due to their excellent recoverability, environmental friendliness, and scale-inhibiting qualities, these materials could be employed as alternatives to the synthetic alkaline compounds used for improved oil recovery.

Keywords: FTIR, Atomic Absorption Spectrometer, phytochemical composition, alkaline flooding, and enhanced oil recovery

¹Assistant Professor, Department of Mechanical Engineering, School of Engineering and Technology, Sandip University, Nashik, Maharashtra 422213

²Assistant Professor, Department of Mechanical Engineering, Sandip Institute of Technology & Research Centre, Nashik, Maharashtra 422213

³Assistant Professor, Department of Mechanical Engineering, Sandip Institute of Engineering and Management, Nashik, Maharashtra 422213

Email: ¹akshay.tajane@sandipuniversity.edu.in, ²yogeshkumar.falak@sitrc.org, ³sachin.Chede@siem.org.in

DOI: 10.31838/ecb/2023.12.s3.146

1. Introduction

It has become necessary to boost oil output in order to fulfil the world's rising energy demand. After primary and/or secondary oil recovery, chemical enhanced oil recovery (cEOR), a tertiary oil recovery technique, is used to further extract residual oil trapped by capillary or viscous forces and left behind in the reservoir, hence enhancing oil output. Alkalis, surfactants, and polymers are just a few of the chemicals that are pumped into the oil reservoir. These substances, which can be employed singly or in combinations, can increase oil recovery by modifying wettability, lowering the interfacial tension, decreasing mobility ratio, or raising the viscosity of the injected fluid. Depending on the crude oil and reservoir type, the efficacy of this chemical flooding procedure has significantly increased oil recovery, allowing for an incremental recovery of over 30%. During water flooding, (Umar & Saaid, 2013) stated that during a pilot test in China, cEOR procedures recovered roughly 24% of the original oil in situ (OOIP). The high cost of the surfactants chemicals, however, is one drawback of the cEOR technology, making the recovery process feasible only when the price of oil rises. More specifically, the use of hazardous chemicals that pose risks to the environment and human health has prompted new laboratory experiments on the use of green, eco-friendly compounds made from agricultural waste. According to research, several of these substances (such as alkaline, surfactants, and polymers) can function as chemical oil recovery agents when changed or refined. However, since these materials, which are frequently regarded as agricultural waste, are renewable, easily accessible, and cost-effective, determining their oil recovery abilities will make their application preferable. It is necessary to identify or characterise these materials to ascertain their composition before the modification process.

2. Research Background

A strong water-soluble base known as an alkali (organic or inorganic) produces hydroxide ions when dissolved in alcohol or water. It is created when alkali metals dissolve chemically. An alkaline solution has a high pH, often more than 7, when dissolved in water.



In caustic flooding, often referred to as "alkaline flooding," an alkali, such as sodium hydroxide, is added to the injected brine. This raises the pH because the alkali dissociate (release OH⁻ ions), changing the wettability of the formation and causing oil displacement. Alkaline flooding's key advantages include lowering interfacial tension and reducing anionic surfactant adsorption, which lowers costs and increases surfactant effectiveness.

The crude oil being used must have a high percentage of acidic components, which will react favourably with the alkali, as this is a fundamental condition for alkaline flooding. 0.3 mgKOH/g of acid number is the bare minimum needed for chemical flooding. Due to the carbonate minerals' adsorption on alkalis, alkaline flooding works best on light-medium crude with API levels ranging from 13 to 35 and in clastic reservoirs rather than carbonate reservoirs. It is not temperature-constrained and works best in brines with low salinity. Alkaline flooding has employed a variety of alkalis in an effort to lessen residual oil saturation. Strong alkalis like sodium hydroxide, potassium hydroxide, and sodium orthosilicate are among them. However, less reactive alkali such as sodium carbonate (pH=10.9 to 11.3), sodium silicate (pH=10.5 to 11.5), and sodium bicarbonate (pH = 9) have emerged as a preferred alternative due to their low pH value (pH=9) and increasing reaction with reservoir rock type, which results in scaling problems, precipitation, chemical consumption, etc. According to (Arensdorf et al., 2011), the production of either carbonate or silicate scales as a result of the interaction of alkali with the rock minerals has remained an issue (2011). Scaling was also identified by (Bachari et al., 2019) as one of the operational problems with chemical flooding in their experimental and field studies. Scaling causes lower permeability as a result of formation and/or injection well clogging. According to (Flaaten et al., 2008), a system's pH is a key determinant in the development of scales. Noting that scaling results from an increase in the concentration of divalent ions caused by alkali chemicals' reactions with formation water and the minerals on the surface of the rock. In order to reduce scaling problems, (Kumar et al., 2010) suggested using sodium tri-polyphosphate (pH=11.2 to 12.3) as a buffer. He said that it should be used in conjunction with other weaker alkalis to effectively produce surfactant and reduce IFT.

In the presence of divalent ions, (Nutting, 1925) looked at the usage of the new alkali sodium metaborate as a sequestering agent. To lessen the impact of divalent ions in the formation brine, recent experiments have combined sodium hydroxide with ethylene diaminetetra acetic acid (EDTA), which functions as a chelating agent. Green scale inhibitors were suggested by (Obuebite et al., n.d.) to prevent scale development during oil production. Moreover, (Ojukwu et al., 2013) recommended the use of moderate pH substances like sodium carbonate during ASP formulations, stating that pH values between 9 and 11 are preferred in order to minimise scaling and emulsion issues. He outlined the typical alkali compounds and their associated pH that are employed during alkaline floods. The usefulness of this in alkaline

floods has also been demonstrated in recent investigations. When potash and *Elaeis guineensis* ash were used in alkaline flooding, (Olsen et al., 1990) found that potash provided a greater recovery. (Sedaghat et al., 2013) 's study employing alkali from locally generated agrowaste demonstrated the efficiency of these materials in boosting oil recovery and preventing scale development.

Agricultural waste products such *Theobroma cocoa* pods, *Elaeis guineensis* bunch ashes, Maple wood ashes, Sugar beet waste, *Musa paradisiaca* peels ashes, potash, Zeamayscob, and *Khaya ivorensis* ashes may be used to produce alkali (Sheng, 2015). The pH values of local and common alkali compounds at 1% weight concentration are shown in Table 1.

Table 1: pH readings for a few common and natural alkali compounds

S/N	CONVENTIONAL ALKALI AGENTS	pH value @ 1% conc.	LOCAL ALKALI AGENTS	pH value @ 1% conc.
1	Sodium carbonate (Na_2CO_3)	11.3	Potash	11.1
2	Sodium metaborate (NaBO_2)	11.1	Palm Bunch Ash	10.0
3	Sodium hydroxide (NaOH)	13.1	Plantain Peel ash	10.9
4	Sodium orthosilicate (Na_4SiO_4)	13.0	Saw dust	9.5
5	Sodium metasilicate (Na_2SiO_3)	12.8	Wood ash	9.5
6	Sodium silicate pentahydrate ($\text{Na}_2\text{SiO}_3 \cdot 5\text{H}_2\text{O}$)	12.6	Banana leaves	10.3
7	Sodium phosphate (Na_3PO_4)	12.0	Cocoa pod ash	10.5
8	Sodium tripolyphosphate ($\text{Na}_5\text{P}_3\text{O}_{10}$)	9.4	Maize cob	10.8
9	Sodium bicarbonate (NaHCO_3)	8.7	Sugar beet waste	10.7
10	Ammonium hydroxide (NH_4OH)	11.6	Never die leaves	9.8
11	Ammonium carbonate (NH_4CO_3)	7.8		
12	Sodium silicate (Na_2SiO_3)	11.6		

Alkali's Recovery Mechanism in Chemical Flooding

Alkaline flooding has been used to increase oil recovery since the early 20th century, but it wasn't until the middle of the 1970s that it really took off and gained widespread acceptance. Sheng (2015) described the Alkaline Flooding Mechanism for Oil Recovery as follows: (i) Wettability reversal; (ii) Emulsification and entrainment; (iii) Emulsification and entrapment; and (iv) Emulsification and coalescence. Mobility control by divalent precipitates and fines is another recovery method.

According to research by (Shutang & Qiang, 2010), alkali plays a special role in chemical flooding because it can produce in-situ surfactants by reacting with the organic acids in the oil. This results in a more negatively charged rock surface because of the higher concentrations of hydroxyl ions that are adsorbed onto the rock surface, which inhibits the adsorption of synthetic surfactants. Researchers in this discipline are becoming more interested in comprehending how these local resources (green fluids) are used as alkali agents and how they are recovered (Stoll et al., 2011). In order to better understand the underlying chemical components and explore potential modifications for enhanced oil recovery and scale-inhibiting processes, certain local alkali agents were described in this work.

Proposed methods and materials

Elaeis guineensis (oil palm bunch), *Musa paradisiaca* (unripe plantain peel), *Bryophyllum pinnatum* leaf extract (never-die leaf), and potash were among the natural agro-wastes that were assessed.

Apparatus: Porcelain crucible, furnace, desiccator, sample cup, beaker, Fourier-transform infrared spectroscopy (FTIR), Atomic Absorption Spectroscopy (AAS), pH metre, Gas-chromatograph Flame Ionization Detector (GC-FID), etc.

Collecting and processing of samples: The experimental study's raw materials for the alkali agents were from a Nigerian open market in the Bayelsa State. They consist of:

- Wood ash is the source of potash, a potassium carbonate salt. It is a frequent ingredient in the creation of natural soap and is a white, water-soluble salt. The northern region of Nigeria is where potash is primarily discovered and extracted.
- Elaeis guineensis* ash is a type of agricultural waste that is mostly composed of calcium, potassium, iron, and aluminium. It is frequently used in the manufacture of soap after being ashes.
- A fleshy shrub with health benefits is *Bryophyllum pinnatum* leaf extract. If the pH is more than 9, it is an excellent base.

d. *Musa paradisiaca* ash; the peel was taken from the market's trash bin, dried, and then ashed. Form determined how these items were prepared. The samples were sun-dried, and the dried samples were then heated to a temperature of about 550 °C in a closed furnace for about 90 minutes to extract the ashes of *Musa paradisiaca* and *Elaeis guineensis*. Because to its hygroscopic nature, potash was carefully air dried before being ground up and put into a container with a tight seal. Before usage, *Bryophyllum pinnatum* leaf extract was cleaned, dried in the sun to reduce moisture, ground, packaged, and sealed in an airtight container to avoid contamination and/or air infiltration.

3. Methods

3.1. pH Value Determination

Using a magnetic stirrer, a solution containing 1g of the chosen local agent in 100ml of distilled water was created. A pH metre was used to determine the solution's pH value, which was then recorded.

3.2. Analysis using a gas chromatography-flame ionisation detector (GC-FID)

One gramme of each powdered sample, 15 millilitres of potassium hydroxide, and 100 millilitres of an ethanol solution were placed in a beaker and left to sit for 24 hours. After that, it was filtered into a test tube and cooked for one hour in a water bath at 60°C.

The separatory funnel received the test tube's contents and transported them there. The injector temperature and volume of the utilised GC with the flame ionisation detector were 280 °C and 2 µL, respectively. The carrier gas, helium gas, was employed and flowed at a rate of 40 ml/min.

The detector was held at a temperature of 320°C while the oven was initially kept at 200°C and then raised to 330°C for 5 min.

The ratio between the area and mass of the internal standard and the area of the detected phytochemicals was used to identify the phytochemicals. In g/g, the concentration of each phytochemical was indicated.

3.3. Analysis using Atomic Absorption Spectrophotometry (AAS)

650 ml of concentrated HNO₃, 20 ml of concentrated H₂SO₄, and 80 ml of perchloric acid were combined.

20 ml of the acid combination and 5g of the sample were digested and maintained in a digestion flask. After heating the digestion flask until a clear digest had been produced, 50 ml of distilled water was added to thin the digest. Only when the light beam in the AAS is directed through the flame to the detector, which then measures the quantity of light absorbed by the atomized element in the flame, was the sample aspirated into the flame and atomized using the AAS. This was done using the American Public Health Association's methodology (Umar & Saaid, 2013)

The concentration of the element in the sample directly relates to the quantity of energy absorbed in the flame.

3.4. Study of Fourier-transform infrared spectroscopy (FTIR)

Each sample was prepared as follows: 10 mg of the powdered sample was combined with a drop of the methylene chloride solvent, and the mixture was then applied to a thin potassium bromide plate. A background spectrum was then chosen and the plate was then inserted into the FTIR spectrometer. In order to allow the infrared radiation beam to flow through the sample, it was put in the path of the infrared radiation frequency. This caused part of the infrared radiation to be absorbed while some of it passed through the sample. It was possible to measure the radiation output and the frequency at which the sample absorbed infrared light. The spectrum was used to determine the peak locations.

4. Results and Discussion

Calculation of pH

The pH values of the chosen materials revealed that they are all alkaline in nature, with pH values all above 7. (Table 2). Due to its impact on the rock's wettability and ability to absorb surfactants, a solution's pH is a more crucial factor in alkaline flooding than viscosity. (Umar & Saaid, 2013) found that using 2-6% maple wood ash as a local source of alkali enhanced the solution's alkalinity (pH), and that its pH value (13.5) at 6% concentration was equivalent to that of 0.5% sodium hydroxide. The use of potash in alkaline flooding was compared to the use of *Elaeis guineensis* (Arensdorf et al., 2011) found that potash provided a greater recovery even under reservoir circumstances due to its higher pH value. Also, the study found that these alkali agents had pH values between 9 and 11 at constant alkaline concentrations (1% wt.), which supports Sheng's conclusion on the optimal pH value range for alkaline floods (2011).

Table 2: Local Materials' pH Values

Samples	pH value
---------	----------

Bryophyllum pinnatum leaf	9.8
Elaeis guineensis ash	10.0
Musa paradisiaca ash Potash	10.9 11.1

Analysis of physicochemical properties

Potash, ashes from *Elaeis guineensis*, ashes from *Musa paradisiaca*, and *Bryophyllum pinnatum* leaf extract all contained magnesium and calcium, the chemical constituents of interest, according to results of elemental analysis using AAS (due to their occurrence in formation brine and on rock surfaces). Its inclusion in the chosen materials suggests that they can chelate these divalent ions. There are less cations for the chemicals to interact with because these materials form complexes with the divalent ions present in the formation brine. The ashes of *Elaeis guineensis* have a little greater potassium concentration than potash and the others, as indicated in Table 3, whereas potash has a

higher level of magnesium, sodium, and calcium. The process of ashing these materials produces a high amount of potassium hydroxide, which is the cause of the high potassium content of all the chosen materials, with the exception of the *Bryophyllum pinnatum* leaf extract. The findings also demonstrate that potash contains more divalent ions than other elements (magnesium and calcium ions). This suggests that potash is more resilient when it comes into touch with these divalent ions found in hard water or on rock surfaces. As these alkalis have significant levels of metallic oxide and the high pH required for better oil recovery, they are the ideal substitutes for manufactured materials.

Table 3: Mineral composition of the Local Materials of Choice

Minerals (ppm)	Potash	<i>Elaeis guineensis</i> ash	<i>Musa paradisiaca</i> ash	<i>Bryophyllum pinnatum</i> leaf
Magnesium	4.503	4.110	4.125	4.040
Sodium	7.624	7.484	7.482	7.376
Potassium	7.840	7.988	7.807	4.898
Calcium	7.899	5.899	6.989	5.999

GC Evaluation

The alkaline materials were characterised by analysis using GC-FID to identify the set of phytochemicals. These chosen materials comprise a variety of phytochemical kinds, including flavonoids, phenols, alkaloids, and saponins, according to the results (Table 4). It was also noted that several of the chosen materials lacked specific phytochemicals and organic compounds. High amounts of alkaloids were detected, favouring their alkalinity. The maximum alkaloid, flavonoid, and saponin content was found in *Bryophyllum pinnatum* leaf extract, whereas *Elaeis guineensis* ash had the highest concentration of water-soluble phenolic phytochemicals compared to the other

samples. Particularly in the *Bryophyllum pinnatum* leaf extract, the presence of saponin suggests the presence of innate surface-active characteristics. It was also noted that the loss of the majority of the organic matter and molecules when these materials were ashed may have contributed to the low concentrations and/or absence of phytochemicals in potash, ash from *Elaeis guineensis*, and ash from *Musa paradisiaca*. Also, as shown in Figure 1, the FID spectrum of the *Bryophyllum pinnatum* leaf extract offers additional proof that the flavonoid phytochemical grade is dominating in this extract. Furthermore highlighting the usefulness of these materials in the process of improved oil recovery was (Bachari et al., 2019)

Table 4: Composition of the chosen materials' phytochemicals

Components	Palm (ug/g)	Bunch Ash	Never-die (ug/g)	leaf	Plantain peel ug/g	Potash (ug/g)	Type of Phytochemical
Proanthocyanin	2.1233		-----		4,5110	1.8091	Anthocyanin
Naringin	9.7126		20.5858		-----	-----	Flavonoids
Oxalate	-----		2.6544		-----	2.2699	Oxalate
Anthocyanin	8.7831		4.8616		2.5712	7.000	Anthocyanin
Ribalinidine	8.4585		13.3318		-----	-----	Flavonoids



Figure 1: Leaf of Brophyllum pinnatum with FID spectrum

FTIR Evaluation

The Bryophyllum pinnatum leaf extract's FTIR spectrum (Figure 2) revealed a prominent wide peak at 3275 cm⁻¹, which is probably caused by the O-H stretching vibrations of the alcohols and phenols with some intermolecular hydrogen bonding potential. The peaks at 2918 cm⁻¹ and 2851 cm⁻¹ are caused by the methylene groups stretching from C to H. The bands at 1622 cm⁻¹, 1562 cm⁻¹, and 1544 cm⁻¹ are caused by a C = C stretch of aromatics and demonstrate a substantial presence of aromatic groups, perhaps as a result of the extract's flavonoid concentration. Alcohol groups' C-O vibrations produce the bands at 1238 cm⁻¹ and 1033 cm⁻¹. A high concentration of hydroxyl groups in the leaf extract is indicated by low transmittance of the O-H stretch and C-O of alcohol.

Figures 3 through 5 show the FTIR spectra of potash, bunch ash from a plantain (*Musa paradisiaca*), and palm (*Elaeis guineensis*) correspondingly. The biomass ashes' spectra reveal some commonalities. The spectra of palm bunch ash and potash show a conspicuous lack of peaks in the 2900–2800 cm⁻¹ band (which is typical for most organic compounds), indicating a low/insignificant quantity of organic matter in the

plant ashes. The existence of some organic stuff in the biomass ash may be indicated by the band at 3033cm⁻¹ in the spectra of plantain peel ash. The O-H stretching vibrations of hydroxides are what cause the bands between 3629 cm⁻¹ and 3887 cm⁻¹. Water that has been connected with or absorbed is shown by the tiny peak between 1640 cm⁻¹ and 1629 cm⁻¹. The vibrations at 1452–1422 cm⁻¹ are probably caused by carbonates with a C–O bond. Similar to the previous peak, the strong peak at 1380cm⁻¹ can be attributable to CO₃²⁻'s asymmetric stretching. Potash and plantain peel ash have bending vibrations of carbonate groups (CO₃²⁻) at 866 - 851 cm⁻¹. The peaks in the biomass ash spectrum between 1115 cm⁻¹ and 796 cm⁻¹ are most likely caused by aluminum-silicon structures. The peaks at 1115 cm⁻¹ and 1041 cm⁻¹ in the spectrum of plantain peel ash, 1060 cm⁻¹ in potash, and 1004 cm⁻¹ are likely caused by Si-O asymmetric stretching vibrations, whereas the peaks between 784 cm⁻¹ and 705 cm⁻¹ are caused by Si-O-Si symmetric bridge stretching vibrations. The biomass ashes' FTIR spectra show that they include significant amounts of hydroxides and carbonates. Alkaline flooding requires these hydroxides, which explains the suitability of these materials for the operation.

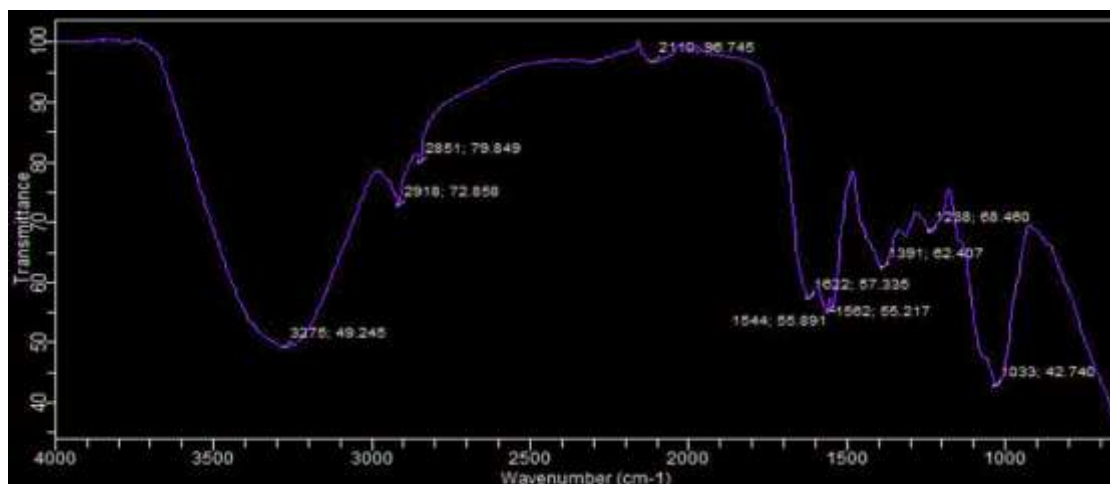


Figure 2: Leaf of Bryophyllum pinnatum, FTIR spectrum

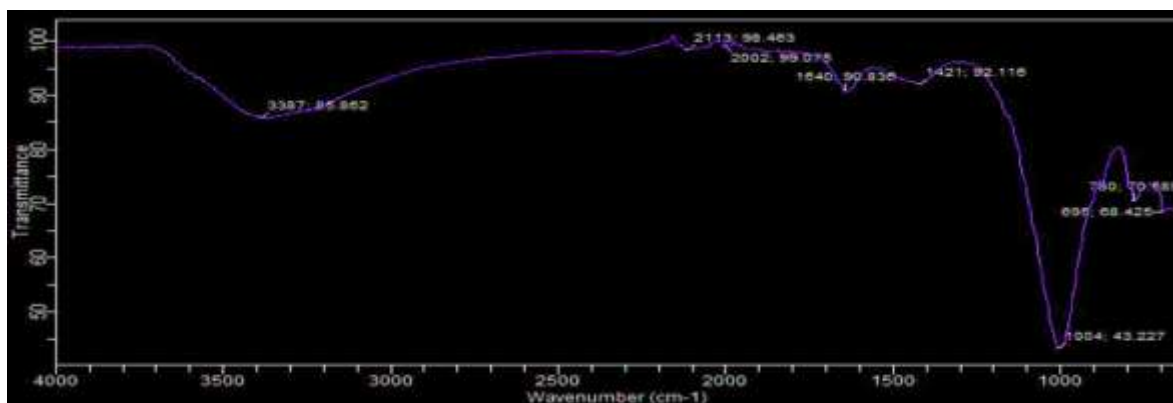


Figure 3: Palm Bunch (Elaeis Guineensis) Ash FTIR spectrum

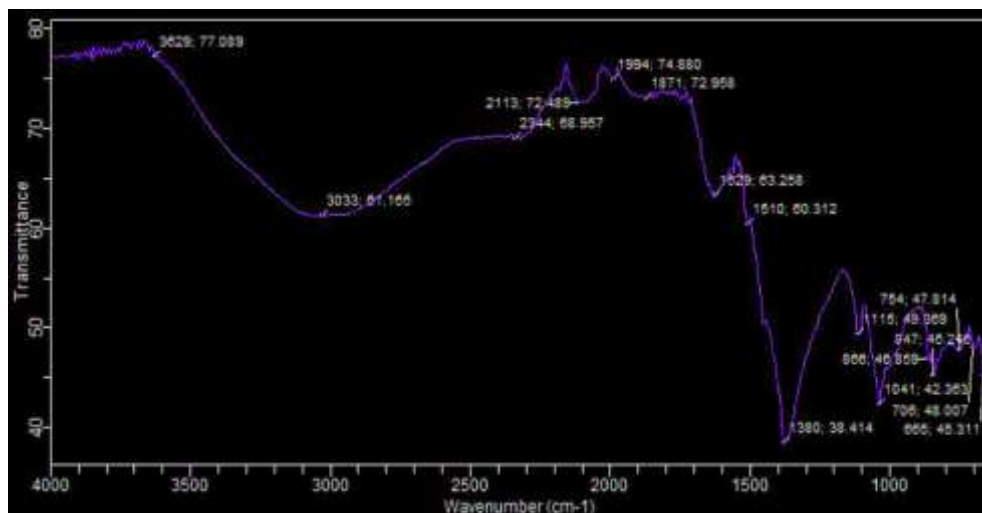


Figure 4: Plantain FTIR spectrum (Musa Paradisica) Ash, Peel

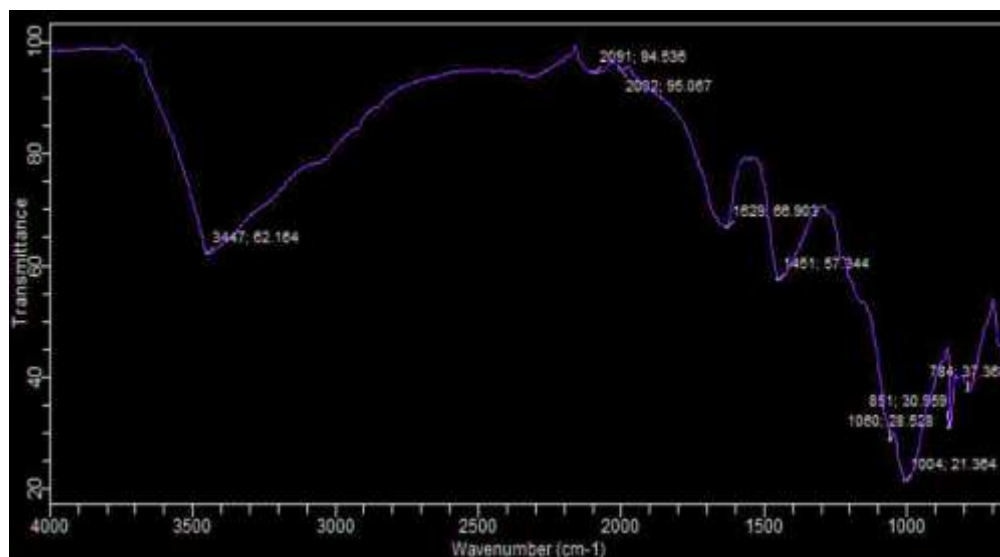


Figure 5: Potash FTIR spectrum

The results of the various analyses show that the chosen natural products are indeed suitable natural alkaline chemicals, with pH values between 9 and 11, which are within the acceptable pH range as recommended by Sheng in 2011 and are comparable to the pH values of traditional alkali chemicals like sodium carbonate and sodium metaborate. According to the phytochemical study, they include the flavonoids, alkaloids, and saponins that are necessary for alkali chemicals to function during chemical flooding. Additionally, the majority of alkaline chemicals currently employed in the oil and gas industry during recovery present a significant issue because they are frequently incompatible with the formation brine in the oil reservoir, leading to scale production that plugs the oil production well, reducing the reservoir permeability and restricting the flow of oil, resulting in a low displacement efficiency. However, as demonstrated by (Bachari et al., 2019) and (Flaaten et al., 2008), who used potash in their experimental study for alkaline flooding, the development and introduction of these natural alkali chemical solutions that have scale inhibiting properties is a novel response to the need for non-toxic, eco-friendly yet effective alkaline recovery agents.

4. Conclusion

- When evaluated as prospective natural alkali oil recovery agents, *Brophyllum pinnatum* (never die leaf), *Elaeis guineensis* ash (palm bunch ash), *Musa paradisiaca* ash (plantain peel ash), and potash are shown to be suitable based on their pH values.
- High concentrations of divalent (calcium and magnesium) ions as well as sodium

and potassium oxides can be found in the chosen natural alkali agents.

- The existence of alkaloids, flavonoids, and saponins in these materials is confirmed by phytochemical analysis, particularly in *Brophyllum pinnatum* (never die leaf), which demonstrates that it possesses both alkaline and surface-active qualities.
- Natural alkali agents are ashed to form potassium hydroxides, inorganic carbonates, and minerals by reducing or destroying the organic molecules that are already present in them.
- These natural alkalis include chemical components that give them scale-inhibiting qualities and make them good oil recovery agents when alkaline flooding is taking place.
- The poisonous and brine-sensitive manufactured alkaline compounds can be replaced with these natural alkalis.

5. References

- Arensndorf, J., Kerr, S., Miner, K., & Ellis-Toddington, T. (2011). Mitigating silicate scale in production wells in an oilfield in Alberta. SPE International Symposium on Oilfield Chemistry.
- Bachari, Z., Isari, A. A., Mahmoudi, H., Moradi, S., & Mahvelati, E. H. (2019). Application of natural surfactants for enhanced oil recovery—critical review. IOP Conference Series: Earth and Environmental Science, 221(1), 12039.
- Flaaten, A., Nguyen, Q. P., Zhang, J., Mohammadi, H., & Pope, G. A. (2008). ASP chemical flooding without the need for soft water.

- SPE Annual Technical Conference and Exhibition.
- Kumar, T., Vishwanatham, S., & Kundu, S. S. (2010). A laboratory study on pteroyl-L-glutamic acid as a scale prevention inhibitor of calcium carbonate in aqueous solution of synthetic produced water. *Journal of Petroleum Science and Engineering*, 71(1–2), 1–7.
- Nutting, P. G. (1925). Chemical Problems in the Water Driving of Petroleum from Oil Sands. *Industrial & Engineering Chemistry*, 17(10), 1035–1036.
- Obuebite, A. A., Eke, W., & Okwonna, O. (n.d.). Phytochemical Characterization of certain Agro-waste as Natural Alkali Agents for Chemical Enhanced Oil Recovery.
- Ojukwu, C., Onyekonwu, M. O., Ogolo, N. A., & Ubani, C. (2013). Alkaline surfactant polymer (local) enhanced oil recovery: an experimental approach. SPE Nigeria Annual International Conference and Exhibition.
- Olsen, D. K., Hicks, M. D., Hurd, B. G., Sinnokrot, A. A., & Sweigart, C. N. (1990). Design of a novel flooding system for an oil-wet Central Texas carbonate reservoir. SPE/DOE Enhanced Oil Recovery Symposium.
- Sedaghat, M. H., Ahadi, A., Kordnejad, M., & Borazjani, Z. (2013). Aspects of alkaline flooding: oil recovery improvement and displacement mechanisms. *Middle East J. Sci. Res.*, 18(2), 258–263.
- Sheng, J. J. (2015). Investigation of alkaline–crude oil reaction. *Petroleum*, 1(1), 31–39.
- Shutang, G., & Qiang, G. (2010). Recent progress and evaluation of ASP flooding for EOR in Daqing oil field. SPE EOR Conference at Oil & Gas West Asia.
- Stoll, W. M., al Shureqi, H., Finol, J., Al-Harthy, S. A., Oyemade, S., de Kruijf, A., van Wunnik, J., Arkesteijn, F., Bouwmeester, R., & Faber, M. J. (2011). Alkaline/surfactant/polymer flood: From the laboratory to the field. *SPE Reservoir Evaluation & Engineering*, 14(06), 702–712.
- Umar, A. A., & Saaid, I. B. M. (2013). Silicate scales formation during ASP flooding: a review. *Research Journal of Applied Sciences, Engineering and Technology*, 6(9), 1543–1555