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Economic Evaluation of Oil Reservoir Emulsion Flooding Fluid Formulated with Palm Oil Mill Effluent and Empty Palm Bunch

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Abstract: *The cost of obtaining foreign chemicals for EOR operations in the Niger Delta are challenging, principally in the face of surging currency exchange rate. Therefore, this research presents the opportunity of recovering more oil from the country`s depleted reservoirs at a cheaper cost with eco-friendly emulsion fluid. The cost of formulating the emulsion flooding fluid with palm oil mill effluent, and empty palm bunch was compared to the cost of formulating a synthetic emulsion with gear oil and sodium lauryl sulphate. Oil was extracted from palm oil mill effluent using a centrifuge after characterization and surfactant solution was prepared with distilled water and ash from burnt empty fruit bunch, then oil/surfactant emulsion sample was formulated in a ratio 30/70. Furthermore, a synthetic emulsion with gear oil and sodium lauryl sulfate was also formulated in a ratio of 30/70. Two Core samples of evaluated geometry were used in this flooding experiment. These crude oil saturated cores were flooded with water, then followed with then followed by flooding with the locally formulated emulsion, and the synthetic emulsion respectively. The results showed that water flooding in the two core samples recovered 58.3% of oil, while the locally formulated emulsion recovered an incremental 35.2% and 37.5% of oil respectively. Lastly the economic analysis of formulating emulsion flooding fluid using waste materials from palm oil mill, and using synthetic materials were carried out. The results revealed that the net present value of investment in formulating synthetic emulsion is N-499,507,552,185.00, while the net present value of using waste materials from palm oil mill is N 26,940,828,073.20. Investment on the production of emulsion of 30/70 ratio using synthetic materials requires a substantial initial investment and generates consistent negative cash flows, leading to a significant loss of 90.89%, but investment in the production of 30/70 emulsion ratio with oil extracted from palm oil mill effluent and palm bunch ash appears viable, with a relatively small yearly investment, positive cash flows for the 10-year period, and a substantial positive NPV. With payback period of 8.17 years and a Return on investment of 122.35%.*

Keywords: Palm oil mill effluent, Empty palm bunch, local emulsion, synthetic emulsion, economic evaluation.

INTRODUCTION

Enhanced oil recovery (EOR) is a technique employed to recover oil that remained in the reservoir after primary and secondary recovery strategies have been exhausted. Izuwa et al (2021). The oil and gas industry,pays more attention to risk and uncertainties due to huge monetary demand involved in its operations. consequently, all oil recovery strategy applied to recovery oil from a hydrocarbon field experience stringent profit analysis. Odo, J. E et al (2024).

When considering an EOR project, If the costs exceed the expected benefits, the project should be abandoned, conducting a comprehensive economic evaluation is crucial for making well-informed decisions regarding enhanced oil recovery projects. A cost-benefit analysis offers a structured approach to assessing the overall expenses and potential returns on investment, enabling stakeholders to weigh the costs against the projected gains and make informed decisions accordingly. (Eleni and Konstantinos,2016.; Olajire et al. 2014)

LITERATURE

Al-Murayri et al. (2018) carried out a cost-benefit evaluation of using local polymers for enhanced oil recovery strategy in Kuwait. The outcome showed that the use of local polymers reduced the costs of enhancing oil recovery by 30%, proving its economical viability. Likewise, an investigation by Kumar et al. (2020) revealed that the application of local surfactant for enhanced oil recovery in India minimized the costs by 25% when compared to synthetic surfactant.

(Nowrouzi et al, 2023., Nowrouzi et al 2024), evaluated the feasibility of using a rapeseed oil-derived anionic polymeric surfactant and chia for enhanced oil recovery from carbonate/sandstone composite reservoirs.The polymer- surfactant solution was formulated and characterized. Temperature stability and salt tolerance The interfacial tension (IFT), viscosity, contact angle, and injection of chemical slugs into the Carbon/Sandstone Composite plugs evaluated. the results, showed that the surfactant remained stable at reservoir temperature and salinity up to 90,000 ppm, and the optimal viscosity was at the critical micelle concentration (CMC) of 4000 ppm, and oil recovery improved by by 26.5%, while water production showed a reduction of 20%.

Dong et al. (2022) formulated two polymer-surfactant solution with different structures. The outcome indicated that the amide fortified structure contains more aquaphobic elements, with the ability of increasing the viscosity, emulsification, salinity-friendly, shear-resistance,and recovers more oil than the second polymer-surfactant solution enforced with the ring group composition.

Wang et al. (2022) Formulated a novel flooding fluid possessing better viscosity and emulsification properties by linking polyvinyl-alcohol with 2-acrylamide-2-methyl propane-phonics acid ($C_7H_{13}NO_4S$) and acrylamide with the ability to increase the viscosity of the displacing fluid twenty-seven times better than conventional polyvinyl-alcohol solutions. Kumar et al. (2016) evaluated the feasibility of Jatropha oil in enhancing oil recovery, and studied Shear thinning behaviour, inter-facial tension alteration, the result from the core flooding experiment revealed a 26% increment in oil recovery.

Chen et al. (2020) recorded a 17.69% improvement displacement efficiency of oil in the hydrocarbon reservoir by formulating a flooding chemical through polymerization process. Wibowo et al. (2021) evaluated the use of palm oil in formulating a polymer-surfactant flooding solution for flooding oil wells through the polymerization of an anionic surfactant to form an emulsion. The result recorded an oil recovery of 84.79%. Priyanto et al (2021) synthesized polymer-surfactant solution for hydrocarbon reservoir flooding fluid from rice husk and polyethelene glycol. The outcome showed that the highest ratio of polyethelene glycol gave the highest oil recovery of 79%. Olajire (2014) evaluated the economic feasibility of using local polymers for recovering more oil from depleted reservoirs in the Niger Delta. The results showed the economic viability of local polymers in enhancing oil recovery by recording a net present value (NPV) of $10 million. Also, Li et al. (2019) studied the utilization of local materials for enhanced oil recovery in China the economic feasibility showed a net present value of $5 million.

Mandal, et al. (2010) evaluated the influence of various values of oil content (5%, 10%, 20% and 30%) in Oil/Water emulsions on reservoir formation during emulsion flooding operation by formulating oil-in-water emulsions using gear oil and sodium lauryl sulphate. injected them into core samples. The outcome of the flooding trials with these emulsion samples demonstrated that the emulsion with 10 % content gave the optimum oil recovery.

Onwukwe et al (2022) studied the effect of irvingia gabonensis with nanoparticles of zinc and alluminium on oil recovery in core samples experiment. Ndem et al (2024) showed that emulsion flooding fluid formulated from palm oil mill effluent and empty palm fruit bunch can recovery more trapped oil after oil recovery through water flooding has become uneconomical.

MATERIALS AND METHODS

The materials used in this experiment are palm oil mill effluent and empty palm fruit bunch,

other materials are:

- Gas chromatograph- mass spectrophotometer (GC-MS)
- Pyrometer (density bottle)
- Liquid Permea-meter flow loop
- Beaker
- Separating funnel
- electric mixer
- Measuring cylinders

- Thermometer
- Flooding apparatus
- Stop watch
- Pump

Methods

Formulation of Emulsion using Ash Solution from Burnt Empty Palm Bunch and Oil Extracted from Palm Oil Mill Effluent

Palm oil mill effluent was characterized using GC-MS, oil was extracted from the palm oil mill effluent using centrifuge to separate the liquids from the solids, water was further removed from oil-water extract using separating funnel and the oil stored in a beaker. The empty palm fruit bunch was dried in an oven then blended homogeneously to reduce the particle size, the blended ash was mixed with distilled water at a ratio of 350g of ash to 500ml of water, this ash solution was filtered to remove undissolved particles. The functional group in the ash solution were determined using Fourier transformation infrared spectroscope (FTIR). The extracted oil from palm oil mill effluent was mixed with the ash solution at room temperature in a ratio of 30/70 by placing the oil extracted from palm oil mill effluent in respective beakers and different volumes of ash solution was added to it in the ratios stated above and labeled accordingly. An electric mixer was used in homogenizing the mixture in order to create smaller droplets of the oil within the surfactant solution for increase of emulsion stability. By placing the formulated emulsion in a Biobase Bk-VX1 , the sample were put into the tube and put in place through the test tube holder rod by pressing into the mixing head. The speed control knob was initialized by placing it at the lowest position, after pushing the ON button, the speed was set at 1200 RPM for 5 minutes and repeated twice. The emulsions thus formed in the respective tubes were then evaluated for stability. The emulsion sample passed through centrifugation test, interfacial tension test, droplet size distribution test, and shear stress at various shear rate.

Preparation of the control emulsion using the works of Mandal (2010)

A standard emulsion was prepared in line with the works of Mandal et al. (2010). In his preparation of the emulsion gear oil was used with sp. Gravity of 0.905, and kinematic viscosity 197 cst. Detergent was equally added to it to improve its recovery efficiency as a surfactant then distilled water. The entire mixture was mixed in a three blade propeller at room temperature. Sodium lauryl sulphate which is an industrial standard surfactant was used. An oil-in-water emulsion sample of 30/70 ratio was prepared in accordance to Mandal .A. (2010). the choice of this ratio is because the works of Mandal .A (2010) highlighted this ratio as producing the best oil recovery from a core flooding experiment. A 1000ml beaker was cleaned and distilled water of 700ml was poured into it. The sodium lauryl sulphate was weighed in a balance, then 0.1g of sodium lauryl sulphate was dissolved in 100ml of water, so 0.7g of the surfactant was dissolved in 700ml of water. 300ml of the lubricant oil bought from a fuel station oil was measured into the same beaker. A magnetic stirrer was applied in mixing the emulsion. The sample was evaluated for viscosity, density using the same method applied to the emulsion samples formulated with oil extracted from palm oil mill effluent and ash solution from palm bunch.

Core flooding experiment

The flooding process took place in a flood scheme apparatus that housed the core, accumulator, core scheme injector. For the purpose of this flooding exercise, our prepared emulsions of 30/70 oil-in-water emulsions were used in addition to the control prepared. Prior to the secondary flooding process with water, original oil in place was obtained by saturating the core with brine and then injecting oil to displace the brine water in the core sample. The oil that settled at the top of the beaker containing both oil and water then formed our primary recovered oil. The saturated sample was inserted into a core holder (rubber butt) and the weight (M_1) was obtained.

The end of the two sides of the core holder was capped with stem heads and one end was connected via tubing to the electrical pump. The plug was flooded thoroughly using crude oil at a flow rate of 2cc/60sec until crude oil was being produced at the receiving end. The stem heads were removed from the rubber butt, and the volume of the brine was read off from the cylinder.

The volume of the brine obtained is the volume of the oil originally in place. The stem heads were reconnected to the rubber butt containing the saturated plug and the reservoir was replaced with a known volume of water. The water was injected using the electrical pump into the core holder at a flow rate of 2cc/60secs until brine breaks through at the receiving end, then the oil recovered were recorded appropriately. Sequentially, the emulsions were used in flooding the core samples with the Control emulsion added. The emulsion sample were injected into the core holder at a flow rate of 2cc/60sec to recover the oil that was not recovered using water-flooding. The injection was continued until there was emulsion breakthrough at the receiving end. The volume of oil recovered from each core sample using respective emulsion sample was recorded and observations were noted. This process was repeated using the other emulsions prepared respectively and the corresponding observation recorded.

RESULTS

Table 1. Chemical characterization of burnt empty palm fruit bunch

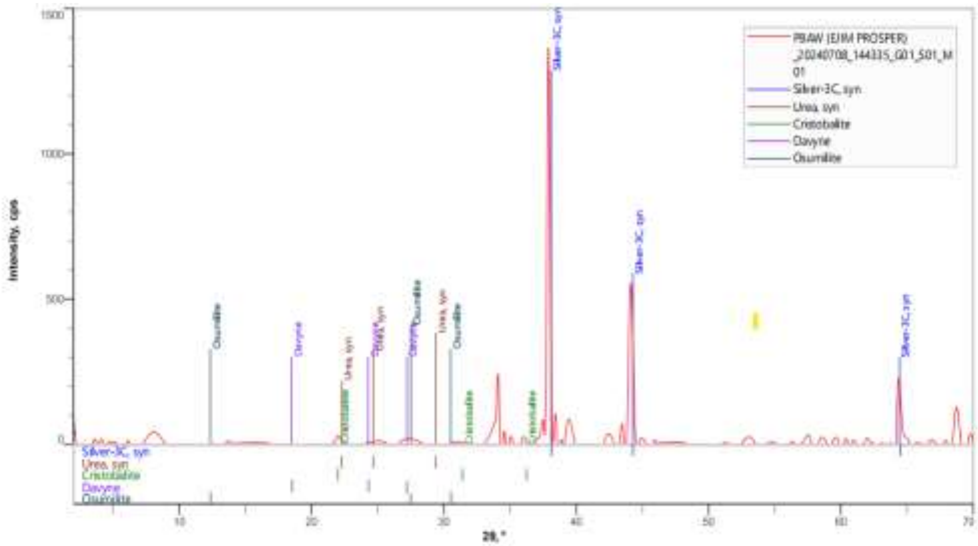
ELEMENTS	CONCENTRATION (g/kg)	CONCENTRATION (%)	pH
Potassium	684.35	68.4	11.0
Sodium	20.16	2.02	
magnesium	6.18	0.62	
phosphorus	15.59	1.59	
Calcium	0.84	0.08	

Table 2: Property of Palm bunch Ash solution

Viscosity (cp)	Density (g/cm3)	API gravity
0.9436	1.0016	24.71

Table 2: Property of Palm bunch Ash solution

PROPERTY	Specific Gravity	Viscosity (cp)	Density (g/cm^3)	Temp oC	pH
VALUE	0.87	10.5	0.90	29	5.5



Graph 1. Phase Identification of Ash solution formulated with burnt palm bunch and water

Table 4 : Properties of the control emulsion prepared using engine oil and sodium Lauryl Sulphate

Property	**Value**
Density (g/cm^3)	1.11
Viscosity (cp)	9.5
Specific gravity	1.05
API	14.5
Temperature	29°C

Economic Analysis of Formulated Emulsion versus Conventional Emulsion

Table 5: Assumptions for Economic Analysis

Annual oil Production (bbl)	Oil Price $	Annual Revenue $	Annual Revenue =N= (1 $ = 1,500=N=)	Discount Rate %	Oil Production Life Span (yr)
100,000	66	6,600,000	9,900,000,000.00	10	10

Table 6: Cost estimate of Emulsion formulation with conventional Material

Materials	Unit	Unit price (=N=)	Quantity	COST (=N=)
Engine Oil	1liter	9500	15,900,000	105,735,000,000.00
Sodium Lauryl Sulphate	1kilogram	4.000	4,770	19,080,000.00
Distilled Water	1 liter	600	4,770,000	2,862,000,000.00
			TOTAL	108,616,080,000.00

Table 7: Cost estimate of Emulsion formulation with Palm Oil Mill Effluent and Palm Bunch Ash

Materials	Unit	Unit price	quantity	COST (=N=)
Palm Oil Mill Effluent	1liter	100	15,900,000	1,590,000,000.00
Palm Bunch Ash	1kilogram	100	4,770	477,000.00
Distilled Water	1 liter	600	4,770,000	2,862,000,000.00
			TOTAL	4,452,477,000.00

Table 8: Cash flow and Present Value of conventional Emulsion at a discount rate of 10%

Year	Investment	Annual Revenue (=N=)	Discount factor	Net Cash Flow	Present Value
0	-108,616,080,000.00	0	1.0000	-108,616,080,000.00	-108,616,080,000.00
1	-108,616,080,000.00	9,900,000,000.00	0.9091	(98,716,080,000.00)	(89,846,272,727.00)
2	-108,616,080,000.00	9,900,000,000.00	0.8264	(98,716,080,000.00)	(80,649,211,099.00)
3	-108,616,080,000.00	9,900,000,000.00	0.7513	(98,716,080,000.00)	(72,959,486,111.00)
4	-108,616,080,000.00	9,900,000,000.00	0.6830	(98,716,080,000.00)	(66,539,320,579.00)
5	-108,616,080,000.00	9,900,000,000.00	0.6209	(98,716,080,000.00)	(60,972,838,497.00)
6	-108,616,080,000.00	9,900,000,000.00	0.5645	(98,716,080,000.00)	(55,993,181,870.00)
7	-108,616,080,000.00	9,900,000,000.00	0.5132	(98,716,080,000.00)	(51,458,365,111.00)
8	108,616,080,000.00	9,900,000,000.00	0.4665	(98,716,080,000.00)	(47,235,544,990.00)
9	108,616,080,000.00	9,900,000,000.00	0.4241	(98,716,080,000.00)	(43,207,672,039.00)
10	108,616,080,000.00	9,900,000,000.00	0.3855	(98,716,080,000.00)	(39,261,739,162.00)
Total	**1,086,160,800,000.00**	**99,000,000,000.00**		**980,716,080,000.00**	(**608,123,623,185.00**)

NPV = N-499,507,552,185.00

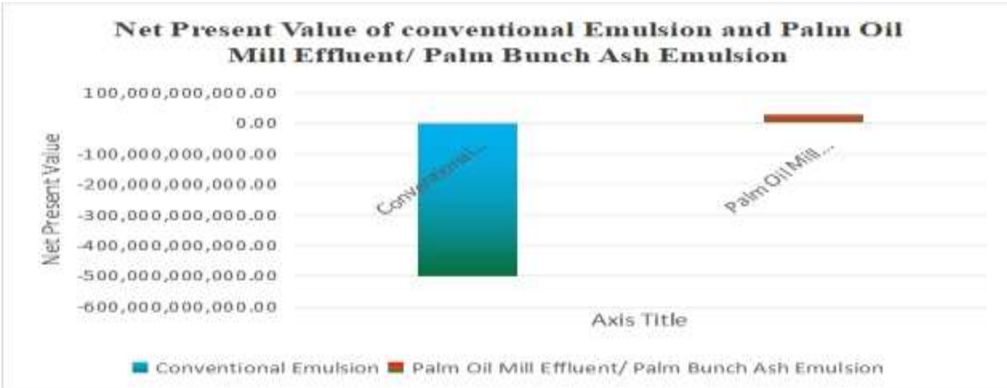
Table 9: Cash Flow Analysis of Emulsion Formulation with Palm Oil Mill Effluent and Palm Bunch Ash

Year	Investment	Revenue	Discount factor	Net Cash Flow	Present Value
0	-4,452,477,000.00	0	1.0000	-4,452,477,000.00	-4,452,477,000.00
1	-4,452,477,000.00	9,900,000,000.00	0.9091	5,447,523,000.00	4,952,343,159.00
2	-4,452,477,000.00	9,900,000,000.00	0.8264	5,447,523,000.00	4,501,833,007.20
3	-4,452,477,000.00	9,900,000,000.00	0.7513	5,447,523,000.00	4,092,724,029.90
4	-4,452,477,000.00	9,900,000,000.00	0.6830	5,447,523,000.00	3,720,658,209.00
5	-4,452,477,000.00	9,900,000,000.00	0.6209	5,447,523,000.00	3,382,367,030.70
6	-4,452,477,000.00	9,900,000,000.00	0.5645	5,447,523,000.00	3,075,126,733.50
7	-4,452,477,000.00	9,900,000,000.00	0.5132	5,447,523,000.00	2,795,668,803.60
8	-4,452,477,000.00	9,900,000,000.00	0.4665	5,447,523,000.00	2,541,269,479.50
9	-4,452,477,000.00	9,900,000,000.00	0.4241	5,447,523,000.00	2,310,294,504.30
10	-4,452,477,000.00	9,900,000,000.00	0.3855	5,447,523,000.00	2,100,020,116.50
Total	**44,524,770,000.00**	**99,000,000,000.00**		**54,475,230,000.00**	**31,393,305,073.20**

Net Present Value = N26,940,828,073.20

Table 10: Table 4.Net Present Value of conventional Emulsion and Palm Oil Mill Effluent/ Palm Bunch Ash Emulsion

Investment	Conventional Emulsion	Palm Oil Mill Effluent/ Palm Bunch Ash Emulsion
Net Present Value	N-499,507,552,185.00	N 26,940,828,073.20



Graph 2: Net Present Value conventional Emulsion and Palm Oil Mill Effluent/ Palm Bunch Ash Emulsion

Table 11: Investment analysis in formulating conventional and palm oil mill effluent emulsion

Investment	**Net Present Value (-N-)**	**Payback Period (year)**	**Return on Investment (%)**
Conventional Emulsion	-N- (499,507,552,185.00)	-	-90.89
Palm Oil Mill Effluent/Palm Bunch Ash Emulsion	N-26,940,828,073.20	8.17	122.35

DISCUSSION

The yearly Investment in the production of the conventional emulsion sample of 30/70 oil/water emulsion requires a significantly higher yearly investment of (-N-108,616,080,000) compared to investment in the production of 30/70 emulsion sample of oil/palm bunch ash solution of (-N-4,452,477,000). Investment in the production of conventional emulsion sample has negative cash flows throughout the 10-year period, while investment in the production of 30/70 emulsion sample with oil extracted from palm oil mill effluent and palm bunch ash solution has yearly positive cash flows.

Net Present Value (NPV) of investment in the conventional 30/70 emulsion sample has a negative NPV -N- (-499,507,552,185.00)), indicating a loss, while investment in the production of 30/70 emulsion sample with oil extracted from palm oil mill effluent and palm bunch ash has a positive

NPV (N-26,940,828,073.20), indicating a profit. Investment on the production of conventional emulsion of 30/70 ratio appears non-viable, as it requires a substantial initial investment and generates consistent negative cash flows, leading to a significant loss of 90.89%, but investment in the production of 30/70 emulsion ratio with oil extracted from palm oil mill effluent and palm bunch ash appears viable, with a relatively small yearly investment, positive cash flows for the 10 year period, and a substantial positive NPV. With payback period of 8.17 years and a Return on investment of 122.35%

Implication to Research and Practice

The core flooding experiment highlighted the ability of emulsion formulated with local materials to enhance oil recovery from Niger Delta depleted wells, it also shows compatibility with the reservoir formation. Furthermore, the economic evaluation shows that enhancing oil recovery with emulsion formulated with palm oil mill waste material is far cheaper than the synthetic or imported materials.the net present value of investment in the production of emulsion for reservoir flooding operation with emulsion from this palm oil mill waste is positive with high return on investment and a good payback period.

CONCLUSION

- Emulsion prepared with palm oil mill waste has shown viability in enhancing hydrocarbon withdrawal.
- The cost of formulating emulsion with palm oil waste is far cheaper than synthetic emulsions

Future Research

Further research should be encouraged to upscale it to field operation

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