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RESEARCH ARTICLE OPEN ACCESS

Laboratory Investigation of Effects of Zinc-Oxide Nano Particle on the Productivity of Apara Field During Microbial Enhanced Oil Recovery (MEOR) Application

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ABSTRACT
The increasing demand of fossil fuel has drawn global attention to finding alternative source of energy. Many laboratory research and field trials have shown MEOR to be very successful. Recent studies have indicated key technological advancement in getting the best out of many recovery processes which is to improve cumulative oil production and ultimate oil recovery. In this work, Zinc-oxide nanoparticle was used to improve the productivity of an oil well in Niger – Delta. Nanoparticle was used at different concentration ranging from 5 grams to 20 grams on the crude. The results obtained shows an increase in oil recovery by 25.33% due to an increase in the nanoparticle concentration. The use of nanoparticle in the improvement of oil recovery is a new trend in the energy sector which rapidly increases oil productivity by acting as a catalyst to speed up oil recovery.
Keywords **-** Zinc-Oxide, Nanoparticle, Productivity, Oil Well and Microbial Enhanced Oil Recovery (MEOR)

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I. INTRODUCTION

Crude oil provides the major source of the world's energy. After using standard oil extraction procedures, a considerable amount of this valuable and non-renewable resource is left in the ground. Furthermore, there is a pressing need to produce more crude oil to fulfill the world's expanding energy demand, hence the importance of advancing enhanced oil recovery (EOR) technologies. These approaches attempt to overcome the major roadblocks to efficient oil recovery, such as limited permeability of some reservoirs, high crude oil viscosity, and high oil-water interfacial tensions, which can result in large capillary forces that keep the oil in the reservoir rock [1]

Microbial enhanced oil recovery (MEOR) is an EOR technology that involves using microbes and their by-products to mobilize oil in a reservoir. MEOR is a process that increases oil recovery by inoculating microorganisms into a reservoir with the goal of causing beneficial effects such as the formation of stable oil-water emulsions, mobilization of residual oil due to reduced interfacial tension, and diverting injection fluids through upswept areas of the reservoir by clogging high permeable zones. Microbial technologies are increasingly being recognized around the world as cost-effective and ecologically benign methods of increasing oil production [2]. Biosurfactants and nanoparticles are two recent methods of enhanced oil recovery. The importance of microbial enhanced oil recovery (MEOR) in the recovery of crude oil cannot be overstated. Microbial Enhanced Oil Recovery (MEOR) entails the production of biosurfactants by microorganisms, also known as microbes, which aid in the reduction of interfacial tension and the formation of crude micelles.

Nanoparticles are in-situ agents for solving reservoir engineering challenges, and their usage in the oil and gas sector is only getting started. Metal oxides such as Tin, Zinc, Aluminum, Magnesium, Iron, Silicon, and Zirconium are among the nanoparticles employed. Nanoparticles have the power to alter reservoir parameters, increasing the reservoir's production rate. Reservoir wettability, crude oil viscosity, and reservoir permeability are some of these qualities.

MEOR stands for microbial-enhanced oil recovery, and it's a new way to get more oil out of existing reservoirs. This technology is far more cost-effective and environmentally favorable than previous EOR techniques. The amount of energy consumed in microbial procedures to improve oil recovery is unaffected by crude oil prices. Microbes can develop autonomously in a variety of

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environments and manufacture huge quantities of useful products quickly from inexpensive, renewable ingredients in large quantities. Microbial bioproducts are often biodegradable as biological agents, resulting in reduced pollution and low toxicity [3, 4]. Biosurfactants are biodegradable, nontoxic, typically varied, and stable under harsh conditions, and injection of partially purified biosurfactants boosted the amount of recoverable oil to 40%. Biosurfactant manufacture can be substantially less expensive because it can be done with biomass waste [5, 6]. The researchers started by isolating, screening, and identifying possible biosurfactant-producing bacteria from a crude oil sample in the reservoir.

II. LITERATURE REVIEW

1. EOR Process

The primary, secondary, and tertiary recoveries are the three main stages of hydrocarbon recovery. This is frequently a sign of a reservoir's sequential production pattern [7]. The basic recovery mechanisms, also known as natural drive mechanisms, are employed during the first reservoir production stage, when only natural reservoir energy is used.

However, this method only recovers a little amount of oil [8] oil recovery from the primary and secondary stages of production is about one-third of the original oil in place (OOIP), which is deemed insufficient and leaves a substantial amount of oil behind during production. The remaining two-thirds of the oil can be recovered in part via tertiary procedures, often known as enhanced oil recovery (EOR) techniques, which are important drivers of incremental oil recovery. EOR is a well-established method for reclassifying reserves that were previously thought to be unrecoverable or dependent.

The key drive for EOR is the possibilities of recovering additional oil economically with its recovery processes and techniques in view, and the ability to turn residual cumulative oil into reserves. This is attained by incapacitating the physical forces that confine hydrocarbons underground [7]. In order to boost or maintain recovery from existing fields, a variety of methods and technologies are applied.

The injection of steam (thermal EOR), chemical-based fluids (chemical EOR), and gases into a reservoir (gas EOR) are all examples of these processes, and microbes (microbial EOR) have recently been used in oil fields. As the injected fluid, gases, or microorganisms interact with the formation rock and oil systems, creating a favorable environment for greater recovery, these processes promote effective displacement of oil towards the producing well, resulting in increased production from matured fields.

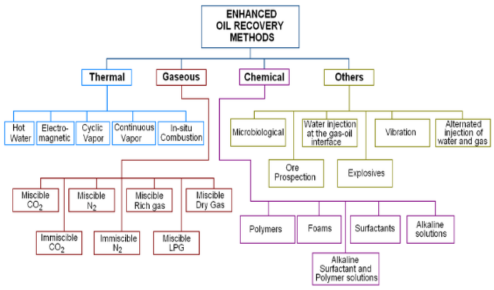

Figure. 1. Simplified classification of EOR methods [7]

2. Thermal EOR (TEOR)

Thermal approaches for oil recovery involve injecting heat energy into oil reservoirs. The temperature of the reservoir is raised significantly in order to obtain a large reduction in oil viscosity. Typically, a change in rock wettability happens during the process, which improves the possibilities of greater oil recovery.

Thermal enhance oil recovery can be used in light oil reservoirs, despite its usefulness in heavy oil formations. Although the environmental footprint of Thermal enhance oil recovery is substantial when compared to traditional oil production, it is likely the most widely employed enhanced oil recovery technology for upsurging production, particularly steam flooding. In-situ combustion (ISC) and steam injection are used in Thermal enhance oil recovery. There are three types of steam injection: cyclic steam stimulation (CSS; huff and puff), steam flooding, and steam-assisted gravity drainage (SAGD).

3. In-situ Combustion

Air is injected into viscous oil reservoirs to generate heat by burning a part of the existing oil in in-situ combustion [9]. The ISC can operate in either a forward or reverse direction, depending on the combustion front. The combustion fronts move toward the injected air (ahead combustion) or away from the air/producing well (reverse combustion) (reverse combustion). In practice, the forward combustion method is used because the hot zone and oil flow away from the injection well and towards the producing well. Forward combustion looks to be more economically appealing than reverse combustion since the heavy ends, or undesirable percentage of the oil cokes, are used as fuel while clean sand is left behind; the generated heat is used for other purposes.

The energy released by the combustion reaction between the injected air and the oil is typically used to recover oil using this process:

i. The oil is ignited, and air is continuously pumped to push the flame front away from the well.
ii. The fluids progress towards the production wells, and the lighter ends are transferred downstream, mixing with the crude oil. ii. Reservoir fluids are displaced at elevated temperatures (600-700°C).
iii. The heavier ends are burned, resulting in a considerable amount of flue gas generation. Permanent improvement of a tarry crude with low thermal efficiency.
iv. In most cases, oil recovery is accomplished through the energy generated by the combustion reaction between the injected air and the oil:

The crude oil the oil is ignited, and air is continuously supplied to keep the flame front moving away from the well.
a. At elevated temperatures (600-700°C), reservoir fluids are displaced.
b. As the fluids approaches the production wells, the lighter ends are transferred downstream, where they mix with the crude oil.
c. The heavier ends are burned, resulting in a considerable amount of flue gas generation.

4. Steam Injection

The injection of steam into shallow, thick, and permeable reservoirs containing high viscosity crude is known as steam injection. Steam flooding, Cyclic Steam Stimulation (CSS), and steam-assisted gravity drainage are all examples of steam injection techniques (SAGD). Steam is injected into specific injection wells during steam flooding to push reservoir fluids to a separate set of producers. The following methods are used to recover oil: Continuous steam injection into the formation. Steam injected into the injection well heats the chamber around it. The chamber expands in the direction of the production well, resulting in a decrease in oil viscosity and significant oil displacement. Through prolonged steam (heat)-oil contact, the injector and producer wells offset the effect of the oil's high viscosity and provide the pushing power for the oil's movement towards the production well. The gravity drainage of hot oil and condensed water has an impact on SAGD [10].

5. Chemical Technique (CEOR)

Chemical EOR (CEOR) approaches involve injecting chemicals into wells to recover oil. CEOR is most suited to formations that are extensively depleted and flooded (i.e. mature reservoirs) [11]. Surfactants, alkali, or their combinations, for example, can dramatically lower the interfacial tension between brine and oil [12] boosting microscopic sweep efficiency at the pore scale. By adding polymers to the injected water, mobility ratios can be greatly enhanced.

The addition of polymer to the injection brine increases the viscosity of the aqueous phase, resulting in better macroscopic displacement due to reduced water under riding [13]. Surfactants improve microscopic displacement efficiency by reducing oil-water interfacial tension and producing oil-water emulsions, which mobilize leftover oil. The addition of alkalis causes the creation of natural surfactants in situ by reacting with the crude oil's acidic components (generally heavy oils). These natural surfactants perform the same job in the reservoir as manufactured surfactants. Polymer, surfactant, alkaline, surfactant polymer (SP), and alkaline surfactant polymer (ASP) floods are the most prevalent CEOR.

6. Alkaline Flooding

Several strategies for alkaline injection recovery have been proposed. Emulsification with coalescence, wettability gradients, oil-phase swelling, stiff film disruption, and low interfacial tension are among them. The chemical nature of crude oil and reservoir rock should be blamed for the occurrence of several processes.

When different crude oils in different reservoir rocks come into touch with each other in different settings, such as temperature, salinity, hardness concentration, and pH, the results can be very diverse. All of the scientists agree, however, that the acidic components in crude oil are the most critical contributor in alkaline flooding. Alkaline flooding is a method of improving recovery by injecting water with a pH of 10–12.

When the aqueous phase and oil phase are in contact, alkaline in the aqueous phase and organic acids, HA in the oil phase migrate into the interface, react and produce surface-active species (petroleum soap). The effect of caustic to the petroleum acids is expressed by the reaction below

$$HA + OH \leftrightarrow A^{-} + H_2O \qquad (1.1)$$

Many researchers have looked into the use of alkaline chemical flooding as an EOR procedure in the lab. It is thought that residual oil is trapped within the crevices between sand grains by capillary and adhesion forces, which are combined with oil viscosity, and that alkaline solutions counteract these forces, allowing the oil to escape. Caustic NaOH has been proposed as a technique for improving water flood oil recovery [14].

They discovered that some crude oils and porous media can be transformed from water-wet to oil-wet given the right conditions of pH, salinity, and temperature. It has been discovered that adding alkali to acceptable crude oil can greatly reduce the interfacial tension. Intermittent alkali flooding, according to [15] can greatly improve oil recovery in oil-wet carbonate reservoirs by lowering the interfacial tension between reservoir fluids and reversing wettability to a more favorable condition.

7. Surfactant Flooding

Surfactants, or surface-active agents, have at least one hydrophilic and one hydrophobic group in the same molecule.

They can diminish interfacial tension between crude oil and brine by becoming adsorbed on the liquid-liquid interface and altering the wetting properties of reservoir rock and fluid as a result of this property.

The expense of surfactant is a major stumbling block to successful surfactant flooding EOR installation [16].

DIT behavior of crude oil and surfactant solution at various salinities and concentrations of 0.8 percent sodium carbonate, as reported by [16].

The surfactant is dissolved in water or oil to create a microemulsion, which produces an oil bank.

The development of an oil bank, as well as the subsequent maintenance of sweep efficiency and pressure gradient by the injection of polymer and chase water, considerably improves oil recovery.

III. MEOR MECHANISMS

Oil recovery can be improved through microbial actions through a variety of mechanisms, including surfactant production and bacterial presence, selective plugging by microorganisms and their metabolites, oil viscosity reduction through gas production or degradation of long-chain saturated hydrocarbons, and production of acids that improve absolute permeability by dissolving minerals in the rhizosphere [17].

As a result, microorganisms can create many of the same compounds that are employed in traditional EOR processes to mobilize oil trapped in reservoirs, and the only difference between EOR and some of the MEOR approaches is likely the way of introducing the substances into the reservoir.

IV. MATERIALS AND METHODS

The procedure used to carry out the microbial enhanced oil recovery in the department of Petroleum Engineering Laboratory, Rivers State University. The following analysis were done; determination of the petro-physical properties of the crude such as (viscosity, density, API gravity, specific gravity), before and after the application of bio surfactants in addition with Nanoparticle (Zinc-oxide) to the crude oil sample. Also include the procedure followed to culture the bacteria which is the bio surfactants for the Microbial Enhanced Oil Recovery (MEOR) process. The property of the crude oil was determined before and after the application of bio surfactants (Bacillus) and nanoparticle (Zinc- oxide) to see how bio surfactants and nanoparticle affect the crude oil property to enhance production.

1. Bacteria (Bacillus subtilis spp) Preparation

The bacteria used for this experiment is prepared through the following means;

i. **Reagents**: The reagents include normal saline for serial dilution process. Ethanol, hydrogen peroxide, Kovac reagent, crystal violet, phenol red, Tetramethyle-phenylendiaminedihychrochloride and biritt reagents. e.t.c
ii. **Media used for the cultivation of bacillus species**: Nutrient Agar (NA) medium was used to cultivate bacillus on total heterotrophic bacteria (T.H.B) according to manufacturer's specification. The medium is a general-purpose media for Bacteria. Two (2) Nutrient broth (NB) for proliferation of bacteria (Bacillus Subtilis).

Preparation of Bacillus species: Serial dilution procedure as described by Obire. O and Wemedu S.A (1996), Ofunne (1999), and Csuro S (1999) was employed for the cultivation of known bacteria (Bacillus Subtilis). About 1 gram of soil sample was transferred into 9ml of sterile normal saline, separately to obtain a mixture dilution of 10^1. The mixture was then diluted through a ten-fold serial dilution process to a maximum of 10^-5. About 0.1ml of the selected dilution were inoculated separately onto the nutrient Agar plate (NA) in duplicate. The inoculated plates were incubated at 37°C for 24 hours. After incubation period the ensuring colonies suspected to be Bacillus were subculture onto a freshly prepared plates of nutrient Agar to obtain a pure culture. The plate was incubated again at 37°C for 24 hours. The incubated selected colonies of bacteria we're late subjected to microscopic examination and biochemical test that proof the real identity of Bacillus.

iii. species. The test includes catalase test, citrate test, starch hydrolysis, motility test, MRVP test, indole test and sugar fermentation test. The sugars are, glucose, manitol, lactose, xylose, maltose. The isolate was further identified based on microscopic morphology and reaction pattern to biochemical and sugar fermentation test.

Proliferation of Bacillus Spp: A code isolate confirmed to be Bacillus species we're retrieved from the slant and inoculated in 1 litre of nutrient broth. The inoculated broth was incubated at 37°C for 24 hours within which the broth attained a high level of turbidity.

Result: Colonies of isolate suspected to be Bacillus species had circular shape, raised elevation, entire margin, big size, shiny appearance, moist texture and white colour. It is a Gram-Positive Rod (GPR) ferment glucose, manitol, maltose, xylose, glycerol and non-fermenter of lactose. It is catalase positive, oxidase positive, citrate positive, motile positive, methyl red positive, but salt tolerant negative, Urease negative, rogesproskan negative and indole negative.

2. Density Determination

Extensive laboratory research was carried out in order to estimate the oil's fundamental qualities.

Procedures

i. Determine the weight of a dry pycnometer that is empty.

ii. Fill the pycnometer halfway with oil and take a temperature reading.

iii. When filled with oil, weigh it and make sure there are no bubbles inside the pycnometer.

iv. Reheat the fluid-filled pycnometer to the new required temperature and repeat the procedure.

v. To compute the density of the liquid, divide the volume of the pycnometer by the filled pycnometer minus the empty pycnometer.

vi. Repeat steps 1-4 for crude oil alone, crude oil recovered with water, crude oil recovered with water and biosurfactants, and crude oil, water, biosurfactants, and nanoparticles.

$$\text{Density (g/cc)} = \frac{\text{filled pycnometer} - \text{empty Pycnometer}}{\text{Volume of pycnometer}} \qquad (1.2)$$

3. Viscosity Determination

i. Clean the viscometer with a suitable solvent and dry it in a stream of clean, filtered or N_2 gas.

ii. The instrument should be cleansed with chromic acid on a regular basis to remove any remnants of organic deposits.

iii. If there is a chance of lint, dust, or other solid material in the liquid sample, it can be filtered out using a sintered glass filter or fine mesh screen.

(Note that with crude oils, this may not be possible.)

iv. Invert the viscometer, immerse tube "A" in liquid, and apply suction to "I," causing the sample to rise to etched line "E."

Return the viscometer to its original position and clean tube "A."

v. Place the viscometer in a holder and in a bath of constant temperature.

6. In the bath, vertical alignment can be achieved by dangling a plumb bob in tube "I."

vi. Using suction, bring the sample into bulb "B" a short way above mark "C."

vii. The efflux time is determined by letting the material to flow freely through mark "C" and timing the passage of the meniscus from "C" to "E."

viii. Repeat steps 7 and 8 to measure efflux time again.

ix. Multiplying the efflux time by the viscometer constant

yields the kinematic viscosity.

Kinematic viscosity (cSt) + density (g/cm3) Equals dynamic viscosity (cp).

$$Viscosity = \left(At - \frac{B}{t}\right)\rho \qquad (1.3)$$

4. Specific Gravity Determination

The hydrometer works on the Archimedes principle, which states that a solid suspended in a fluid will be lifted up by a force equal to the displaced fluid's weight.

As a result, the lighter the liquid (i.e., the lower its specific gravity), the deeper the body dives, as more liquid is necessary to equal the body's weight.

A hydrometer is typically composed of glass, with a cylindrical stem and a bulb that is weighted with mercury or lead shot to keep it afloat.

The test liquid is poured into a tall container, usually a graduated cylinder.

The hydrometer is carefully lowered until it floats freely in the liquid.

The point at which the liquid's surface comes into contact with the hydrometer's stem is noted.

A scale is frequently positioned inside the stem of a hydrometer, allowing the specific gravity to be read directly.

$$\text{Specific gravity} = {}^{\text{Density of oil}}/_{\text{Density of water}} \qquad (1.4)$$

5. Microbial Enhance Oil Recovery Process

This is a laboratory set up for enhanced oil recovery; this set up can employ a variety of enhanced methods such as water, air, and nanoparticles, but in this case bio surfactants and nanoparticles are used to improve crude recovery.

The set up consists of a carbon dioxide cylinder (CO_2) that acts as the reservoir pressure, this cylinder is connected to a 12liter metal tank that serves as the reservoir, a pipe runs from this tank to a tap handle (which serves as the well head valve), and a pressure gauge is used to measure the pressure.

Figure. 2. Microbial Enhance Oil Recovery Setup.

V. RESULT

1. Density

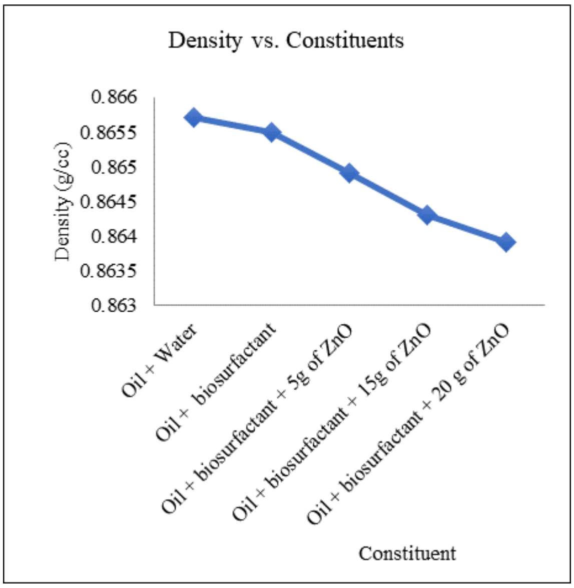

Figure. 3. Plot showing the variation of Density of the Constituents

Regardless of the individual element added to the primary combination (Oil + Water), the density trend in the fig 3 reveals that the change in this characteristic was modest.

The density remained steady, hovering around 0.86 g/cc. A substance's relative density is a quality that remains constant under certain conditions. Given that water has a density of 1 g/cc, the examined crude oil combination has a relative density of 0.86, which is lower than water (relative density of water is 1). The crude oil mixture will float on water, indicating that it is a light oil.

2. **Viscosity**

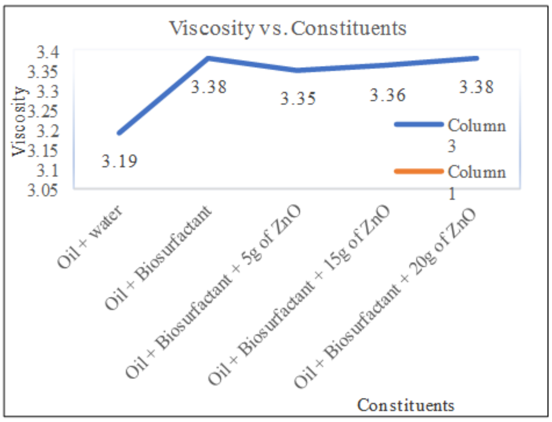

Figure. 6. Graphical Relationship between Total Volume of Reservoir Fluids (US gallon) Recovered for each Constituent.

Fig 4, 5 and 6 the effects of zinc oxide (ZnO) nanoparticles on oil productivity during Microbial Enhanced Oil Recovery (MEOR) applications. The continued addition of a higher proportion of ZnO nanoparticles will result in a significant increase in the volume of oil recovered, fig 8. When comparing quantities of oil and total amount of reservoir fluids recovered, the same studies can be used to evaluate the performance of the applied zinc oxide nanoparticles.For example, out of 1.88 US gallon, 0.63 US gallon of oil was recovered for the penultimate constituent (Oil + biosurfactant + 20g of ZnO).When these values are compared to the initial volume of oil recovered for the primary mixture (Oil + Water), which is 0.51 US gallon out of the 2.38 US gallon total volume of reservoir recovered, the efficacy of using zinc oxide nanoparticles to increase oil productivity during Microbial Enhanced Oil Recovery (MEOR) projects becomes clear. As a result, the overall results of this laboratory experiment demonstrate the ability of microorganisms to breakdown heavy crude oil and lower viscosity.

3. Flowrate

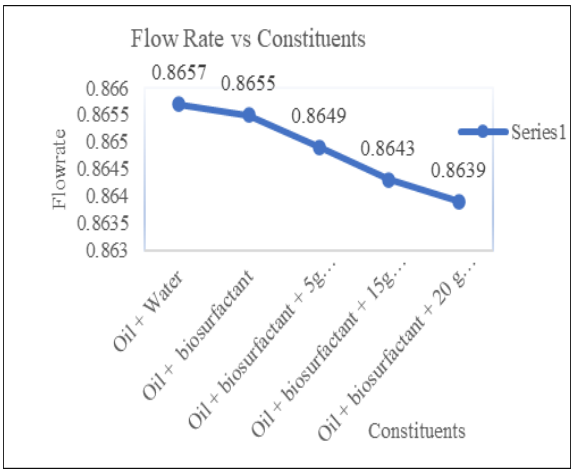

Figure.7. Graphical Relationship Showing the Oil Producing Rates (USgal/min) Derived for each Constituent.

Increased oil producing rates were reached when a higher amount of zinc- oxide nanoparticles was added to the original mixture, as shown fig 7. As a result, the efficacy of using zinc oxide nanoparticles to boost oil production rates during Microbial Enhanced Oil Recovery (MEOR) projects is demonstrated. The efficacy of combining zinc oxide nanoparticles with biosurfactants in producing more oil in oil reservoirs at a very low cost is also seen in table 1.

Table 1: Microbial Enhanced Oil Recovery (MEOR) Experimental Results

Constituents	Volume of Oil Recovered (L)	Volume of Oil Recovered (US gal)	Total Volume of Reservoir Fluids Recovered (L)	otal Volume of Reservoir Fluids Recovered (US gal)
Oil + Water	1.96	0.51	9.0	2.38
Oil + biosurfactant	1.88	0.49	8.42	2.24
Oil + biosurfactant + 5g of ZnO	1.37	0.36	7.9	2.09
Oil + biosurfactant + 15g of ZnO	2.14	0.57	7.6	2.01
Oil + biosurfactant + 20g of ZnO	2.38	0.63	7.1	1.88

VI. CONCLUSION

This study examines the effects of nanoparticles on the productivity of an oilfield (Apara) during the application of Microbial Enhanced Oil Recovery (MEOR). It elucidates how the use of nanotechnology to a specific oil field aids in hydrocarbon recovery, with the Microbial Enhanced Oil Recovery (MEOR) technique as the key focus. The Apara oil field experiment was successful in providing insight into the requirement for incorporating nanoparticles to improve productivity performance during Microbial Enhanced Oil Recovery (MEOR) applications.

The zinc oxide (ZnO) nanoparticle type is used in the study framework for the analysis. The, zinc oxide (ZnO), demonstrated its importance in enhancing the production of the oil field. After the injection of zinc oxide (ZnO) nanoparticles, very major changes in fluid characteristics were found. This serves as a baseline for the effective application of other nanoparticles in boosting oil field productivity. It was also discovered that the biosurfactant and zinc oxide (ZnO) nanoparticles work together to achieve this goal. According to most studies, when the concentration of nanoparticle-surfactant increases, interfacial tension drops.

As a result, the traditional method of mixing these particles for this purpose is strongly recommended. In the other hand, Microbial Enhanced Oil Recovery (MEOR) is a promising and environmentally benign recovery method. It is a sustainable recovery method due to its small environmental footprint.

VII. CONTRIBUTION TO KNOWLEDGE

This research presents a framework or model for enhancing oil field productivity and recovery, emphasizing the advantages of nanoparticles in this regard. Although the focus of this research is on a Microbial Enhanced Oil Recovery (MEOR) initiative, similar knowledge of nanoparticle effects on other recovery processes is encouraged.

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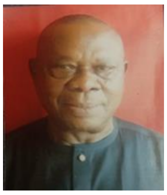

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