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Viscous Oil Recovery with Aluminium Oxide Nanoparticles Using the 2D model: An Experimental Approach

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ABSTRACT

Capillary forces, inappropriate mobility ratio & reservoir heterogeneity account for trapped oil in reservoirs after the secondary process. To optimise the recovery of this left behind Oil, improved oil recovery (IOR) techniques need to be applied, which can be economically demanding. The use of the particles of the Oxide of Aluminium precisely Aluminium Oxide Nanoparticle (Al_2O_3 NP) technology for IOR is a recent innovation that is in short supply in literature as Al2O3 NP help oil mobilization by reducing the interfacial tension between oil & water. Laboratory experiments were carried out using a Hele-shaw cell, and a 2-D glass cell with glass beads as the porous media to investigate the flow and viscous oil recovery by Nanoparticles injection. The experimental work was in six folds with six slugs labelled A, B, C, D, E and F respectively. Results obtained indicated that flooding with the nanoparticles in a water-ethanol mixture (that is Slugs A and D) produced high recovery compared to that of Nanoparticles (NP) in brine (that is Slugs B and E only) and NP in ethanol (that is Slugs C and F only) because aluminium oxide is a hydrophilic nanoparticle and would merge with water and allow the ethanol to reduce the interfacial tension, compared to using brine. Therefore, the dispersing fluid plays a vital role in oil recovery by NP slugs.

1. Introduction

Oil recovery from a reservoir is driven by reservoir energy. This energy may either be primary energy (which is as a result of the initial state of the reservoir) or supplementary energy (which is as a result supplementing the reservoir energy by some external means). Supplementary energy may be due to gas injection, water flooding, injection of chemicals, thermal method etc. Usually, reservoirs are produced first by primary energy and then later (when the reservoir pressure drops to the extent that it can no longer drive production) by supplementing the reservoir energy. Although in some reservoirs (e.g. viscous or heavy oil reservoirs) supplementary energy (e.g. thermal method) is directly applied as the primary energy cannot drive production. For most reservoirs, vast amounts of unrecovered oil (often greater than 65%) remain after production using their primary energy. The question of how to recover such oil remains a technical and economic challenge. For now, the contribution of renewable energy seems to be insignificant in meeting the increasing world energy demand; therefore, it is extremely important to continue to explore new ways to maximize the production from existing oil fields through enhanced Oil recovery methods. Compared with other types of thermal and non-thermal EOR methods, using Al_2O_3 NP oil recovery technology results in lower residual oil saturation, equipment investment and operation costs [1, 2].

NPs are particles with size range from 1nm to 100nm. They show some useful characteristics as IOR agents when compared to the available injection fluid used in traditional IOR processes such as gas, water and chemicals. Two of the most important concerns in chemical processes are pore plugging (whereby injected chemicals trapped in porous media result in reduction of formation permeability) and injection cost. Commonly used NPs, such as SiO_2, TiO_2 and Al_2O_3 are in the order of 1 nm–100 nm, which is small compared to pore and throat sizes. This allows easy flow of these NPs through porous media without severe permeability reduction due to trapping of NPs. Furthermore, as a result of the ultra-small size of NPs, they possess the ability to go through some pores where conventional injection fluids are not capable to. Thus, NPs can contact more unswept zones, and increase the macroscopic sweep efficiency. Also, NPs are very cost effective and environmentally friendly compared to chemical substances making them preferable for IOR at oilfields. A number of experimental research works have been conducted on chemical IOR technique in West Africa [3-19]. But due to the aforementioned characteristics of NPs, they provide many potential solutions to the existing challenges faced by traditional EOR/IOR methods. Extensive research in Nanotechnology commenced in the 1980's and since then it has continued to be a modern wonder of scientific discovery. [20] studied the effect of four nanoparticles (Al_2O3, TiO_2, SiO_2, and NiO) on the recovery of heavy oil in sandstones. Some flooding experiments were carried out with the use of four nanoparticles at various concentrations. The experiments by SiO_2 and by Al_2O_3 resulted into greater recovery as compared with the base recovery, water injection. SiO_2 increased the recovery by 0.958%, while Al_2O_3 increased the recovery by 4.895%. In view of the fact that both SiO_2 and $Al2O_3$ resulted into more oil recovery, they decided to mix both nanoparticles and do a flooding experiment where they noted a tremendous oil recovery that is more than that of water injection recovery by 23.724% [21, 22, 24]. Nanotechnology has shown a possibility to answer different challenges in oil and gas business. Nanoparticles have been utilized in subsurface applications due to their ability to alter certain properties in the formation. Recent work done in Niger Delta on Nanoparticles technology for oil recovery includes the work of [23]. This study used a Hele-shaw model to test the ability of aluminium oxide to displace heavy Oil and improve its recovery. The Hele-shaw cell is made of closely spaced parallel sheets of glass, a viscous fluid confined between the glasses. The flow of a real fluid between the two closely spaced parallel plates is generated by a pressure gradient applied across the ends of the plates, and the spacing is sufficiently small to ensure that the viscous forces dominate. The main objective of this research is to investigate the displacement efficiency of Aluminium oxide NP using a Hele-shaw cell in recovering oil during tertiary IOR.

2. Methodology

This section presents the approach deployed in this research. The details of the experimental procedure using Hele-shaw cell and mathematical model were all procedurally presented. The experimental work is in six folds termed test A, B, C, D, E and F. The test A and test D were mixtures of the nanoparticles with ethanol-water, Test B and E consisted of the mixture with ethanol and Test C and F were with brine only.

2.1 Materials Used and Fluids Properties

a. Pump

Brine, mineral oil and then the chemical slug were injected into the cell by using a continuous flow pump through the top right port of the cell. The pump was operated under a constant flow-rate condition of 3cm³/min. The produced fluids were discharged at ambient conditions through the left bottom port, and collected in 10 cm³ glass cylinders. Produced samples were acquired at fixed interval of one minute within each flooding process.

b. Camera

In addition to recovery, images were also acquired throughout each flood using a Sony a7 II Mirrorless digital camera with 24.3-megapixel.

c. Nanofluid

Six slugs were prepared and used; Slug A was prepared using the concentration of 0.3g of Aluminium oxide and 5cc of water and ethanol, for Slug B, 0.3g of Aluminium oxide in 5cc of brine and for Slug C, of 0.3g of Aluminium oxide in 5cc of ethanol. Also, Slug D was prepared using the concentration of 0.5g of Aluminium oxide and 5cc of water and ethanol, for Slug E, 0.5g of Aluminium oxide in 5cc of brine and for Slug F, of 0.5g of Aluminium oxide in 5cc of ethanol.

d. Mineral Oil

The crude oil used for the experiments was from a field in Niger Delta, Nigeria. The oil was blackish brown in appearance with a viscosity of 178cp, a density of 0.9415g/cc, a specific gravity of 0.9415 and an API gravity of 18.8.

2.1.1 Experimental Procedure

In the Hele-Shaw cell, the study of the displacement fronts of the Nano fluids with the oil was observed. It represents a large, simple, single-pore method of evaluating and comparing solutions for the purpose of identifying the important physical factors of oil for displacement from porous media.

The Hele-Shaw cell used for these oil displacement experiments was constructed from glass. The two flat parallel plates were separated by a Teflon gasket and held together with 12 buyor clips. The cell has an external dimension of 28 cm x 22 cm and an effective (internal length) of 22 cm x 16 cm. The plates are separated by a gap of 0.0429 cm measured by a digital venier caliper /and the thickness of each glass plate is 0.8 cm. The entire constructed cell was held-up by four clamps and centralized by line plumes. Injection of fluids is through the top left corner of the model, and production is from the bottom right corner providing a diagonal flow path through the system with a variable cross-sectional area. This in turn allows for visualization of fingering and bypassing during displacement tests.

(i) Water saturation (Imbibition)

After Hele-Shaw cell preparation and assembly, it was saturated with water. Part of the objective of imbibition is to completely saturate the cell with water and eliminate air, thus mimicking the initial condition before oil migration. This was done by saturating the whole cell with water which amounted to 30cc, so that the water displaces air in the cell hence avoiding trapping air in the pore spaces. Trapped air may result in having a three phase system (air, oil and water) after drainage instead of a two-phase system (oil and water).

(ii) Oil Saturation (drainage)

After water flooding or Imbibition process, oil flooding or drainage process was performed in order to saturate the cell with oil. This technique of oil flooding enabled us to determine initial oil saturation

(iii) Chemical flooding

After the drainage process the Oil was then swept for 10mins each using each of the six prepared nanoparticles slugs (A, B, C, D, E and F). The recovery and cumulative oil recovery after each minute when using each slug were recorded as shown in the results section.

2.2. Mathematical model

The equation below can be used to determine two phase water oil flow in porous media of which are conservation equation and constitutive equation. Assuming there's no mass transfer

$$\frac{\partial(\varphi\rho\alpha s\alpha)}{\partial t} = -\nabla\cdot(\rho\alpha\mu\alpha) \qquad \alpha = w, o \tag{1}$$

$$\mu\alpha = -\frac{kkr\alpha}{\mu\alpha}(\nabla\rho\alpha - \rho\alpha g\nabla z), \ \alpha = w, o \tag{2}$$

Where,
φ is the porosity of the medium
ρ_α is the phase density (kg m^3)
s_α is the phase saturation
μ_α is the phase velocity (m/s)
w is water (wetting phase)
o is oil (non wetting phase)
K is the absolute permeability(m^2).

$$S_W + S_O = 1 \tag{3}$$

$$P_C = P_O - P_W \tag{4}$$

And the total velocity is,

$$U_t = U_o + U_w \tag{5}$$

$$U_t = -k(\lambda_t S\nabla\rho_w + \lambda_o S\nabla\rho_C) + K_\chi Sg\nabla z \tag{6}$$

Where

$\lambda_\alpha S = k_{r\alpha} S / \mu_\alpha$ is the mobility

$\lambda_t S + \lambda_w S$ is the total mobility

Therefore, water velocity is

$$\mu_w = f_o \mu_t + \lambda_w K\left(f_o \nabla \rho_c\right) + \lambda_w f_o k \nabla \rho g \nabla z \quad (7)$$

Where $\nabla \rho = \rho_w - \rho_o$

3. Results and Discussion

The result of the experimental work is presented below in Tables 1 and 2. From Table 1, Slug A, was observed to have the highest recovery compared with Slug B and Slug C because the Aluminium oxide when positively charged will hold off the water in the system as the hydrophilic part since it has affinity for water while the lipophilic part which is the oil will react with ethanol to further reduce the interfacial tension acting on the oil and water allowing the oil to easily flow. Figure 2 below, shows the amount of oil and water obtained from flooding with nanoparticlesin water, ethanol or both (ethanol-water)as the dispersing fluid. Each recovery was obtained from flooding the fluid for 60 secs each, with a total of 300 secs to achieve the maximum number of oil that can be extracted from the cell with a constant speed. From left to right as the first recovery and last as arranged in the image above, the first recovery having pure volume of oil, from the third flooding shows less volume of oil recovered and more volume of water which means as with time the initial recovery is far more larger than the latter due to the fact that the nanoparticle tends to form precipitate.

Table 1. Flooding Result with 0.3g conc. Aluminium oxide

time (mins)	Oil volume recovered from flooding with slug A (cc/mins)		Oil volume recovered from flooding with slug B (cc/mins)		Oil volume recovered from flooding with slug C (cc/mins)	
	recovery after each minute	cumulative recovery	recovery after each minute	cumulative recovery	recovery after each minute	cumulative recovery
0	0	0	0	0	0	0
1	4.0	4.0	1.5	1.5	0.1	0.1
2	3.6	7.6	0.6	2.1	0.1	0.2
3	3.2	10.8	0.5	2.6	0.2	0.4
4	2.2	13.0	0.2	2.8	0.0	0.4
5	0.8	13.8	0.4	3.2	0.1	0.5
6	0.1	13.9	0.4	3.6	0.1	0.6
7	0.2	14.1	0.6	4.2	0.2	0.8
8	0.2	14.3	0.3	4.5	0.2	1.0
9	0.2	14.5	0.4	4.9	0.1	1.1
10	0.1	14.6	0.4	5.3	0.1	1.2

Table 2. Flooding Result with 0.5g conc. Aluminium oxide

Time (Mins)	Oil volume recovered from flooding with slug D (cc/mins)		Oil volume recovered from flooding with slug E (cc/mins)		Oil volume recovered from flooding with slug F (cc/mins)	
	Recovery After Each Min	Cumulative Recovery	Recovery After Each Min	Cumulative Recovery	Recovery After Each Min	Cumulative Recovery
1	6.6	6.6	4.1	4.1	2.7	2.7
2	6.0	12.6	3.2	7.3	2.5	5.2
3	4.5	17.1	2.8	10.1	2.3	7.5
4	3.8	20.9	2.3	12.4	2.0	9.5
5	3.2	24.5	1.9	14.3	1.3	10.8
6	2.9	28.0	1.7	16.0	0.7	11.5
7	2.4	30.4	1.4	17.4	0.2	11.7
8	1.8	32.2	0.7	18.1	0.2	11.9
9	1.5	33.7	0.4	18.5	0.1	12.0
10	1.3	34.0	0.4	18.9	0.1	12.1

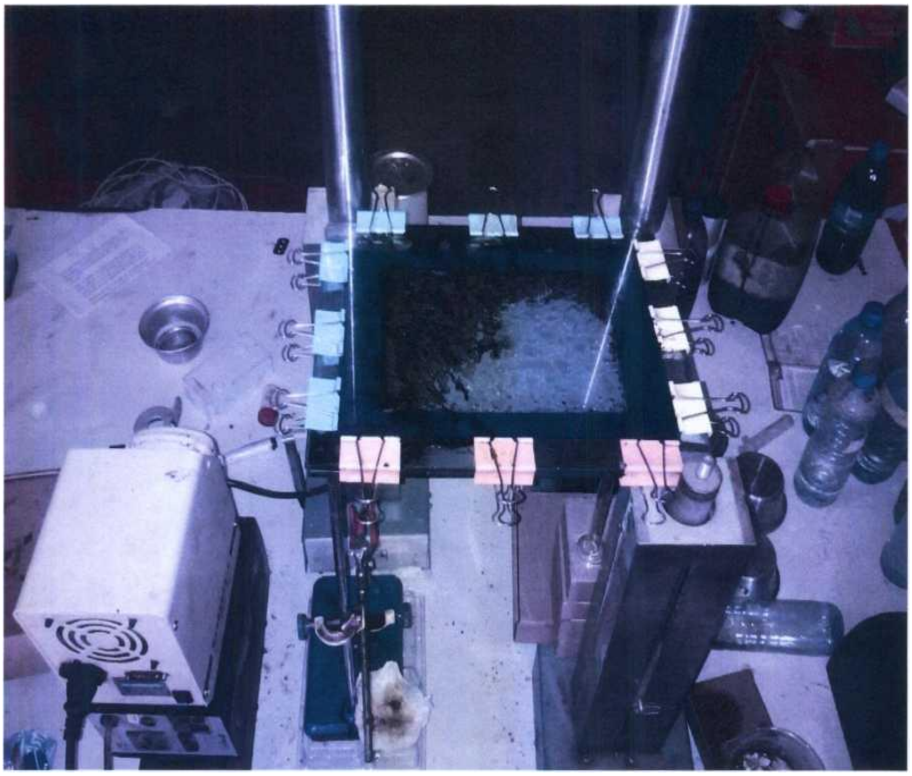

Figure 1: During Nanofluid displacement

Figure 2. Recovery of Oil after flooding

The Figure 3 shows a graphical representation of the plot of oil recovery against time when dispersing nanoparticles with concentration 0.5g in different dispersing media (ethanol-water, water only and brine only). It was observed that the highest recovery was gotten when using ethanol-water mixture as the dispersing fluid (Slug D).

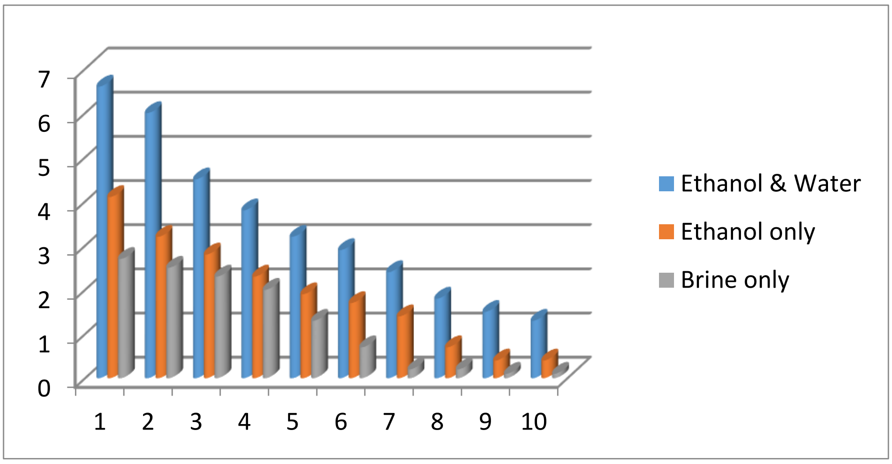

Figure 3. Oil recovery vs time (Nanoparticles conc of 0.5g,)

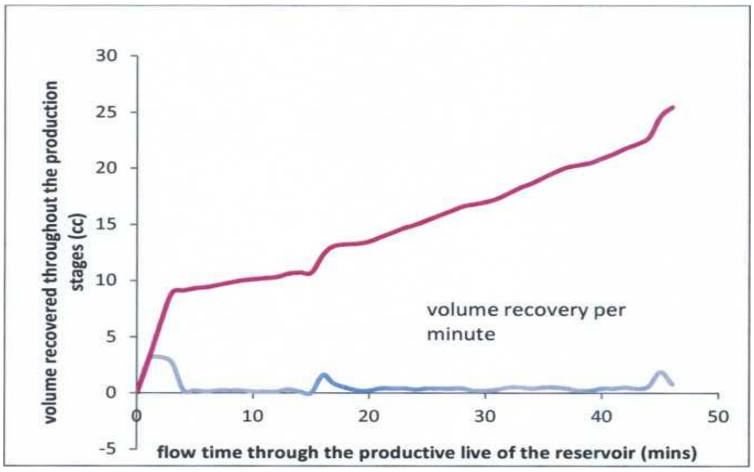

Figure 4: Graph of Total Oil recovery from the reservoir Modelled against Total Productive Life of the Reservoir

Figure 4 shows the profile of entire production life of the Hele-shaw cell as simulated through the injection time of 10 minutes. There was an initial or early region of very steep slope; this describes the early production period before breakthrough. The Oil recovery in this period is usually very high.

4. Conclusion and Recommendation

Nanotechnology has attracted lots of interest recently, there have been various studies that have taken place in regards to the applications of nanoparticles in EOR. This study attempts to summarize how aluminium oxide NP is most applicable and how it can be mixed with dispersing fluid.

From the above results, using aluminium oxide NP in distilled water and ethanol as dispersing agent is a preferable mixture as ethanol reduces IFT between oil and water compared to using brine. This combination can reduce oil viscosity, reduce IFT between oil and water. Nevertheless, it should be noted that ethanol as a fluid without the nanoparticles also improves oil recovery because it reduces the interfacial tension between oil and water. These results indicate that for any nanoparticles to be used for IOR, the dispersing medium must be considered as it could impact positively or negatively on the recovery. Caution should be taken into consideration when using the nanoparticles with brine as IOR. We also do like to recommend further studies on the effect of Temperature on the recovery potential of the Nanoparticles.

Nomenclature

NP	Nanoparticles
IFT	Interfacial Tension
IOR	Improved Oil Recovery
W	water (wetting phase)
O	oil (non wetting phase)
K	absolute permeability
EOR	Enhanced Oil Recovery
P_C	Capillary Pressure
S_W	Water Saturation
S_O	Oil Saturation
U_t	Total Velocity
U_o	Oil Velocity
U_w	Water Velocity

Greek letters

φ	porosity of the medium
ρ_α	phase density (kg m3)
s_α	phase saturation
μ_α	phase velocity (m/s)

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