SALINITY EFFECT ON SURFACTANT-ASSISTED ZINC OXIDE NANOPARTICLES FOR ENHANCED OIL RECOVERY

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ABSTRACT

Several studies have focused on the advantages of applying nanotechnology to the enhanced oil recovery (EOR). This is because nanoparticles are unique due to their small size and large surface area. Metal oxide nanoparticles, including zinc oxide, have been proven to have favourable effects in EOR applications. However, the instability of nanoparticles is one of the most common issues. It has been established in the literature that using a surfactant with nanoparticles can stabilize the latter, lower the oil/water interfacial tension, and alter the wettability of reservoir rocks. It is also common knowledge that chemical EOR is affected by the salinity of formation water. Thus, the objectives of this study were to investigate the effects of salinity on zinc oxide nanoparticles with sodium dodecyl sulphate (SDS) over the interfacial tension and wettability, as well as to compare the recovery of oil by displacing sand packs with water, SDS, ZnO NPs with SDS, and the mixture of SDS, ZnO NPs, and NaCl. Particle size analysis (PSA) and zeta potential were determined to evaluate the size and stability of ZnO NPs before and after adding SDS. The surface tension for SDS was measured to identify the critical micellar concentration (CMC). The interfacial tension and contact angle were measured for different concentrations of nanofluid at ambient temperature and pressure. The concentration range for ZnO NPs was 0.02 to 0.1 wt%, while that for NaCl was 1000 to 30,000 ppm. The results showed that the size of the zinc oxide nanofluid decreased from 406.6 to 308.3 nm after adding SDS. The stability of ZnO nanofluid was confirmed to be improved after mixing with SDS through zeta potential readings of -11.1 mV to -53.3 mV. The CMC for SDS was recorded at 0.2 wt%. The optimum IFT value of 6.25 mN/m was obtained using a mixture of 0.2 wt% SDS, 0.06 wt% ZnO NPs, and 30,000 ppm NaCl. Meanwhile, the lowest contact angle of 45.6 º was achieved using a mixture of 0.2 wt% SDS, 0.06 wt% ZnO NPs, and 20,000 ppm NaCl. Oil recovery after water flooding was 36.1% of the original oil in place (OOIP), while the oil recovery after SDS flooding and SDS with zinc oxide NPs flooding recorded 52.3% and 58.3% OOIP, respectively. Ultimately, the mixture of SDS, zinc oxide NPs, and NaCl can recover up to 60.5% OOIP. The nanofluid mixture was found to be effective in EOR applications.

ABSTRAK

Beberapa kajian telah memberi tumpuan kepada kelebihan mengaplikasikan nanoteknologi kepada pemulihan minyak yang dipertingkatkan (EOR). Ini kerana zarah nano adalah unik kerana saiznya yang kecil dan luas permukaan yang besar. Nanopartikel oksida logam, termasuk zink oksida, telah terbukti mempunyai kesan yang menggalakkan dalam aplikasi EOR. Walau bagaimanapun, ketidakstabilan nanozarah adalah salah satu isu yang paling biasa. Telah ditetapkan dalam literatur bahawa menggunakan surfaktan dengan nanozarah boleh menstabilkan yang terakhir, merendahkan ketegangan antara muka minyak/air, dan mengubah kebolehbasahan batu takungan. Ia juga diketahui umum bahawa EOR kimia dipengaruhi oleh kemasinan air pembentukan. Oleh itu, objektif kajian ini adalah untuk menyiasat kesan kemasinan pada nanozarah zink oksida dengan natrium dodesil sulfat (SDS) ke atas ketegangan antara muka dan kebolehbasahan, serta membandingkan pemulihan minyak dengan menyesarkan pek pasir dengan air, SDS, ZnO NPs dengan SDS, dan campuran SDS, ZnO NPs, dan NaCl. Analisis saiz zarah (PSA) dan potensi zeta ditentukan untuk menilai saiz dan kestabilan NP ZnO sebelum dan selepas menambah SDS. Ketegangan permukaan untuk SDS diukur untuk mengenal pasti kepekatan micellar kritikal (CMC). Ketegangan antara muka dan sudut sentuhan diukur untuk kepekatan cecair nano yang berbeza pada suhu dan tekanan ambien. Julat kepekatan untuk ZnO NPs ialah 0.02 hingga 0.1 wt%, manakala untuk NaCl ialah 1000 hingga 30,000 ppm. Keputusan menunjukkan bahawa saiz zink oksida nanofluid berkurangan daripada 406.6 kepada 308.3 nm selepas menambah SDS. Kestabilan cecair nano ZnO disahkan bertambah baik selepas dicampur dengan SDS melalui bacaan potensi zeta -11.1 mV hingga -53.3 mV. CMC untuk SDS direkodkan pada 0.2 wt%. Nilai IFT optimum 6.25 mN/m diperoleh dengan menggunakan campuran 0.2 wt% SDS, 0.06 wt% ZnO NPs, dan 30,000 ppm NaCl. Sementara itu, sudut sentuhan terendah 45.6 º dicapai dengan menggunakan campuran 0.2 wt% SDS, 0.06 wt% ZnO NPs, dan 20,000 ppm NaCl. Pemulihan minyak selepas banjir air adalah 36.1% daripada minyak asal di tempat (OOIP), manakala pemulihan minyak selepas banjir SDS dan SDS dengan NP zink oksida banjir masing-masing mencatatkan 52.3% dan 58.3% OOIP. Akhirnya, campuran SDS, zink oksida NP dan NaCl boleh memulihkan sehingga 60.5% OOIP. Campuran cecair nano didapati berkesan dalam aplikasi EOR.

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LIST OF ABBREVIATIONS

CA	-	Contact angle
CEOR	-	Chemical enhanced oil recovery
CTAB	-	Cetyltrimethylammonium bromide
EOR	-	Enhanced oil recovery
IFT	-	Interfacial tension
MWCNT	-	Multi walled carbon nanotube
NaCl	-	Sodium chloride
NPs	-	Nanoparticles
OOIP	-	Initial oil in place
ppm	-	Part per million
PSA	-	Particle size analysis
PV	-	Pore volume
SDS	-	Sodium dodecyl sulfate
ZnO	-	Zinc oxide

LIST OF SYMBOLS

ΔP	-	Pressure difference
L	-	Length
K	-	Permeability
Q	-	Injection rate
μ	-	Viscosity
Φ	-	Porosity
A	-	Cross section area

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

The need for natural resources is growing rapidly as industrialization expands. Most available oilfields have already been discovered, and it is difficult to develop commercially viable new resources. Thus, one objective of oil companies is to increase the recovery factor of mature oilfields by the use of new enhanced oil recovery (EOR) techniques. (J. A. Ali et al., 2019; Ali et al., 2018).

The Production of crude oil from a reservoir commences with primary recovery (internal energy) methods, then secondary recovery processes (water and gas injections) initiates when that energy or pressure is starting to decline substantially. Yet, about two-thirds of the original oil in place (OOIP) persists in the pores of the rock. Hence, it was proposed to employ enhanced oil recovery methods that are more effective., such as chemicals injection, miscible gas injection, thermal recovery, and microbial EOR (Yakasai et al., 2021).

Chemical enhanced oil recovery (CEOR) included the injection of different types of chemicals, such as alkaline, surfactant, polymer, and combinations between them. The mechanisms for improving the oil recovery in CEOR involved diminishing the interfacial tension (IFT), oil viscosity reduction, wettability modification, and oil swelling. Conventionally, surfactant flooding has played a crucial role in enhanced oil recovery by decreasing oil-water interfacial tension (IFT), modifying the wettability of oil phase towards a water-wet condition, and emulsifying crude oil. However, its implementation is limited because of adsorption into the rocks, high cost, and poor performance at harsh conditions of reservoir, namely, high salinity and high temperature (Johannessen & Spildo, 2013). As a result, new technologies were developed in order to overcome those problems.

Nanoparticles have demonstrated remarkable benefits in the field of EOR applications as compared to conventional CEOR chemicals. Their small size (1-100 nm) enables them to pass through formation pores that are unreachable to bigger substances without being stuck. Their large surface energy and reactivity can alter the characteristics of fluids and rocks to boost oil displacement. Also, they are modifiable to incorporate multiple functionalities.

Nevertheless, applying nanoparticles in EOR have some drawbacks such as, the agglomeration and precipitation of nanoparticles in porous media which leads to core plugging and hence reduce the permeability and oil recovery. So, many experiments on nanoparticle-surfactant mixtures were conducted and proven to have superior EOR performance as the surfactant is capable to stabilize the nanoparticles (Chen et al., 2019; Suleimanov et al., 2011; Zhao et al., 2018).

In general, nanoparticle applications in EOR may be classified into three distinct groups, nanofluids, nanocatalysts, and nanoemulsions (Liu et al., 2022). Nanocatalyst refers to the oil recovery technique of injecting the nanoparticles as a catalyst during steam injection in heavy oil reservoirs. (Hashemi et al., 2014). The nanoemulsion, on the other hand, is a kind of conventional emulsion with a size range of 50–500 nm. It refers to the method of using nanoparticles to stabilize the emulsion and eliminate some drawbacks of typical emulsions. (Mandal et al., 2012). Nanofluids are suspensions formed by mixing nanomaterials with various liquid solutions known as basic fluids, including water, surfactant, glycol, and ethanol. Because of their unique spreading and functioning mechanism, nanofluids have gained the most attention among the three nanotechnology categories for EOR. (Sharma et al., 2016).

1.2 Problem Statement

silica-based nanomaterials were commonly utilised to improve oil recovery (EOR), but in recent years, metal oxide-based nanoparticles, such as zinc oxide, have been proven to have significant positive effects on reservoir conditioning, such as interfacial tension reduction (Rezk & Allam, 2019), wettability alterations (Adil et al., 2020), and oil viscosity reduction (Adil et al., 2017).

In addition, many researchers have reported that salinity can affect the performance of different types of nanoparticles. (Sadatshojaei et al., 2019) have examined the effect of electrolytes of silica nanofluid on wettability and interfacial tension, while (Nowrouzi et al., 2019) have included three metal oxide nanoparticles in their study, namely, (TiO_2, MgO, and γ-Al_2O_3). They implemented a comprehensive comparison to demonstrate how the IFT changed when saline water from the Karanj reservoir was diluted 10 times.

Moreover, (Shuaibu et al., 2022) have studied the synergetic impact of zinc oxide nanoparticles and ionic surfactants (SDS and CTAB) over the surface and interfacial tensions. They compared the interfacial properties using only one concentration of the salt (355 ppm).

However, the influence of varying salinities on zinc oxide (ZnO) nanoparticles with SDS is still unclear. Therefore, this work has investigated how the salt content affects the interfacial tension (IFT), wettability and oil recovery.

1.3 Research Objectives

The objectives of the research are:

1. To investigate the effects of salinity on zinc oxide nanoparticles with sodium dodecyl sulfate (SDS) over the interfacial tension.

2. To evaluate the effects of salinity on zinc oxide nanoparticles with sodium dodecyl sulfate (SDS) over the wettability.

3. To compare the recovery of oil by displacing sand packs with water, SDS, ZnO NPs with SDS, and the mixture of SDS, ZnO NPs and NaCl.

1.4 Scopes of the Study

In this study, all of the experiments were conducted at room temperature (25 ^{o}C) and under atmospheric pressure (14.7) psi using paraffin oil as the oil phase. A metal oxide type of nanoparticles, namely zinc oxide (ZnO), was characterized individually and also when mixed with an anionic surfactant, which is sodium dodecyl sulfate (SDS). The characterizations included the particle size analysis (PSA) and the zeta potential.

The nanofluids were prepared by adding progressively ZnO NPs powder to SDS and NaCl to achieve a desired concentration. The interfacial tension for SDS was measured to identify the critical micellar concentration (CMC) using concentrations ranges of 0.05 to 0.5 wt%. In order to evaluate the IFT and wettability mechanisms, 5 concentrations of ZnO NPs (0.02, 0.04, 0.06, 0.08, 0.1 wt%) and 5 concentrations of NaCl (1000, 5000, 10000, 20000, 30000 ppm) were employed.

Moreover, two types of porous media were utilized: glass beads with a size range of (150-212 μm) were compacted in sand pack models. And 10 plates of sandstone (with a diameter of 5 cm and a thickness of 0.5 cm) were used for contact angle measurement.

1.5 Significance of The Study

There are only a few studies done on zinc oxide nanofluid-based surfactants. So that the outcome of this research is expected to close the research gap of the influence of salinity on ZnO nanofluid. Moreover, information about the dynamic size and stability of ZnO NPs was obtained. So, it can serve the enhanced oil recovery (EOR) in terms of making IFT reductions and wettability alteration more effective. In addition, the information gained about the surfactant and nanoparticle mixture may also benefit the oil and gas industry, potentially assisting drilling operations, corrosion inhibition, demulsification, cleaning, and transportation.

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