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Identifying the Role of Emulsion and Nano-emulsion for Predicting the Residual Heavy Oil Recovery

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Abstract

The energy sector as well as daily needs of our day-to-day life depends majorly on the utilization of crude oil and its derived products. Therefore, to overcome the basic demands it is mandatory to extract crude oil from existing matured reservoirs. In this work, we have investigated the mechanistic studies of emulsification as well as nano-emulsification and identifying their role on heavy residual oil recovery. The heavy was oil emulsified using surfactants and polymer which were stable up to 24 hours and this assists in improving the trapped residual oil displacement efficiency, thereby reducing the saturation of residual oil inside the reservoir. On the other hand, when nanoparticles were introduced in the same surfactant-polymer system, nano emulsions were observed whose stability were enhanced at a greater rate (up to days) and thus further assist in improved the residual oil recovery. It was observed that average size of the nano-emulsion in microns were smaller (with a greater number of droplets) as compared to emulsion. This phenomenon thereby enhances the stability period and diverts the displacing fluid to cover more area of the reservoirs resulting in higher oil recovery due to higher sweep efficiency. Moreover, core flooding experiments conducted showed an oil recovery of 18% (residual oil in place, RIOP) and was enhanced to 26% RIOP when nanoparticles were deployed in the system.

Keywords

Emulsion, Nano-emulsion, Stability, Core flooding, Oil Recovery

1. Introduction

The escalating demand in crude oil production is governing the price of the crude oil in the international market. Therefore, petroleum industries are in a process to produce large quantity of crude oil to generate more revenue, especially when the price of crude oil barrel is high. There exist, the conventional production methods which are known as primary and secondary water flooding techniques. These combined, accounts to a maximum of 30-35% of original oil in place (OOIP) recovery. The oil and gas industries are exploring numerous available advanced techniques with an aim to overcome the limitations in crude oil productions. Those techniques thereby can be termed as enhanced oil recovery (EOR) (Olajire, 2014; Phukan and Saha, 2022; Sheng, 2013).

Chemical enhanced oil recovery is one of the branches of EOR techniques which play a major role in recovering residual oil when the existing energy in the reservoir undergoes exhaustion and additional water flooding results in viscous fingering effect. Similarly, there exist other EOR schemes such as microbial, thermal, solvent and others. The selection of appropriate EOR methods depends on several factors like reservoir area, thickness, depth, porosity, permeability, crude oil properties (oil saturation, API gravity, acid value, viscosity), reservoir fluid, reservoir salinity and temperature, reservoir rock characteristics, etc.

Surfactant-based flooding under chemical EOR is one of the successful and promising choices for reservoirs to recover residual oil. Surfactant results in emulsification of crude oil/heavy crude oil which is a major factor in deciding the oil movement inside the reservoir rock pores. This emulsification is not new and was detected way ahead in the early 1930s which was then imposed to different directions as chemical and pharmaceutical, medicines, drugs, paints, foods, rheology, etc. At present, there are several successful implemented surfactant/emulsion flooding projects in pilot as well as field scale executed in various part of the world. The ultimate focus is on the movement of trapped oil in the pores of the reservoir rock which is governed by two major factors. This includes the interfacial properties between fluid-fluid interaction present inside the reservoirs, and the solid (reservoir rock) – fluid interactions. The reduction in interfacial tension between oil and surfactant aqueous phase produces emulsification which reduces the viscous fingering effect as introduced while performing economical secondary water flooding. The modification thereby enhances the areal sweep efficiency covering enormous part of the reservoirs, ultimately providing higher oil recovery (Saha et al., 2021; Saha et al., 2018a; Saha et al., 2018b; Saha et al., 2019; Saha et al., 2018c). The enhancement in oil displacement efficiency through the pores is further assisted by the wettability alteration of the reservoir rock to favourable water wet conditions from initial intermediate or oil wet conditions.

However, surfactant flooding is challenging as it can undergo severe adoption due to interaction between surfactant molecules and reservoir rock (solid-fluid interactions). Several factors like rock category, salinity, temperature, etc can govern the adsorption mechanisms (Abbas et al., 2020; Hou et al., 2022; Liu et al., 2021; Saha et al., 2017). If such observation is not considered, then the process may fail badly due to higher losses of such costly chemicals. Thus, while selecting the optimum surfactant slug formulation, the surfactant loss should be incorporated accordingly.

Researchers have investigated some methods to overcome the major surfactant adsorption losses problems which can thereby make the process more feasible as well as economical. This includes the use of nanoparticles in surfactant/available EOR schemes which can reduces the surfactant loss issues and additionally shows improvement in the recovery factor (Joshi et al., 2022; Kumar et al., 2022; Lashari et al., 2022; Wu et al., 2017). Though, nanoparticles have shown promising results, there are inadequate literature works on the topic of nano-emulsion predicting the higher oil recovery and their interconnections. The proposed article can deliver the insights of emulsion vs nano-emulsion which is expected to attract large number of audiences from research background and oil production industries working in the relevant field/areas. Therefore, for large pilot/field implementations, this articles will provide guidelines and add up on the existing literature gaps.

Hence, in this study, the importance of emulsification and nano-emulsification were addressed and the governing factor which decides the cumulative oil recovery were identified. The factors that produce the higher oil displacement efficiency inside the reservoir was estimated by core flooding experiments and their corresponding oil recovery were demonstrated.

2. Materials and Methods

2.1 Materials

The dead crude oil samples were collected from Assam Oil field in India and its physio-chemical properties is shown in Table 1. Anionic surfactants such as sodium dodecyl sulfate (SDS) and sodium dodecyl benzene sulfonate (SDBS) were acquired from Merck Specialities Pvt., Ltd., India and Sigma-Aldrich Chemicals Pvt., Ltd., India respectively. Alpha olefin sulfonate (AOS) anionic surfactant was purchased from Pkd. & Mktd. by BRM Chemicals. Non-Ionic surfactant Triton X-100 and hydrophilic silica nanoparticles were supplied by Sisco Research Laboratory Pvt. Ltd. Finally, sandparticles used for core flooding experiments were procured from local construction sites.

Table 1. The properties of crude oil collected from Assam oil field, India

Crude oil	Acid Value (mg KOH/g sample)	Surface Tension (mN/m)	Density (Kg/m^3)	Viscosity @ 30ºC (mPa s)	API Gravity (^{O})
Light to Medium	2.94	27	892	13.8	27º

2.2 Methods

The methods adopted for screening of surfactants (anionic/non-ionic) were based on emulsification studies. It is because, surfactant with higher potential to emulsify the crude oil can reduce the viscous fingering effect as encountered during secondary water flooding. The emulsification process was executed by mixing crude oil with surfactant (anionic/non-ionic) solutions in transparent vials using rotaspin at 3:7 ratio (Saha and Phukan, 2023; Saha et al., 2018a). The emulsions were then processed to identify the average droplet size with whole process as described in our previous studies (Saha and Phukan, 2023; Saha et al., 2021; Saha et al., 2018b; Saha et al., 2019; Saha et al., 2018c). In a similar way, crude oil and nanofluid (surfactant and nanoparticles mixture) solutions were mixed for the formation of nano-emulsion. More details regarding stability of suspended nanoparticles to achieve stable nanofluid solutions can be found in our previous publications (Saha et al., 2021; Saha et al., 2018b).

The core flooding experiments were then conducted using sandpack. The detail preparation of sandpack and core flooding experimental procedure are explained in our publications (Saha and Phukan, 2023; Saha et al., 2018b; Saha et al., 2018c). The flooding experiments were conducted at room temperature (at 30 ºC) in a core reactor of 3.9 cm diameter and 11 cm length. Initially, brine/reservoir formation water was injected until the sandpack is saturated. Then crude oil was injected until wate cut < 1%, to reach reservoir crude oil saturation of 80 – 85%. The system with such pressurized (800 psi) and saturated condition was then kept ideal for 1 day to reach close to reservoir condition. Water flooding (2 PV) is then injected to estimate secondary water flooding oil recovery and then surfactant/nanofluid flooding (0.5 PV) followed by (1.5 PV) chase water flooding to estimate the oil recovery using surfactant (emulsion) flooding or nanofluid (nano-emulsion) flooding.

The schematic diagram as shown in Figure 1, provide the describes of the whole system in order to estimate the residual oil recovery involved by emulsion as well as nano-emulsion.

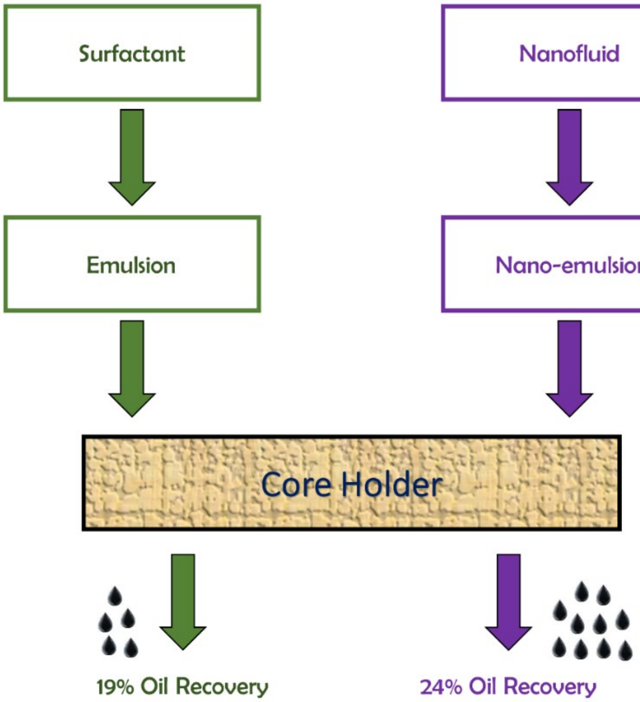


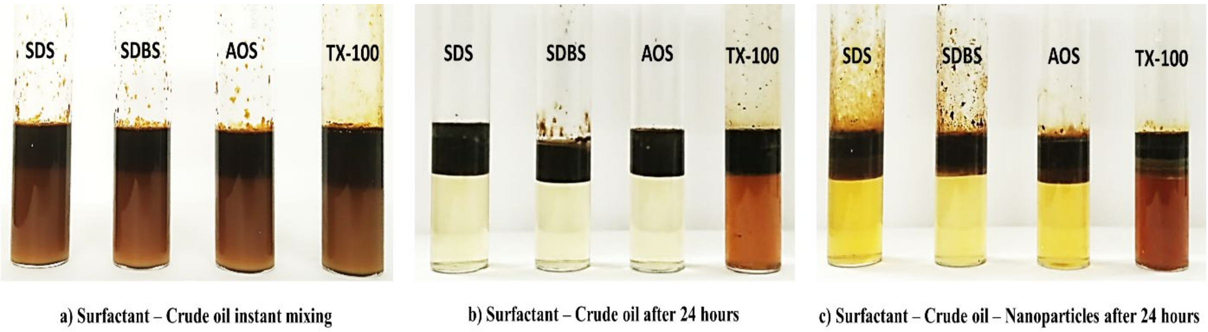
Figure 1. Schematic diagram to understand the potential of emulsion and nano-emulsion towards improvement in residual oil recovery.

3. Results and Discussion

3.1 Emulsion vs Nano-emulsion

The emulsification of crude oil using three different surfactant (SDS, SDBS, AOS and TX-100) in which the concentration of surfactant was kept much above its CMC (0.25% for each), were examined as shown in Figure 2 (a-c). Figure 2a shows the emulsification obtained immediately after mixing the sample. The observation illustrates that all the surfactant samples were helpful in interacting with the crude oil and undergo emulsification at the very instant they were mixed. However, the emulsification stability (after 24 hrs) were varied with each surfactant as depicted in Figure 2b. The differences in emulsion stability could be due to the electrostatic forces encountered between the oil-water droplets. Tx-100 must have undergone high electrostatic repulsion forces which does not allow the oil droplets to bridge/coalescence and thus high stability was detected. The other surfactants showed more or less similar electrostatic forces (attraction or repulsion) and therefore, there stability were similar. Moreover, the other possibilities could be due the steric hindrance formation with Tx-100 which governs the coalescence droplets and thus introduces better emulsion stability (Saha et al., 2018a).

However, when SiO_2 nanoparticles of 0.1 wt% was introduces in the same system (nanofluid), the emulsion stability behaviour were enhanced as illustrated in Figure 2c. The enhancement in the stability was due to the adsorption of nanoparticles at the oil-water interface. The adsorbed nanoparticles with proper packing of surfactant molecules at its surfaces, reduces the droplet coalescence due to higher electrostatic repulsive forces. Additionally, nano-emulsion induces by nanoparticles were much stable as compared to normal emulsion, which could be due to the accumulation of higher number of surfactant molecules at the oil-water interface as assisted by nanoparticles, thereby reducing the interface dissimilarities. Thus, the improvement of emulsion stability with nanoparticles is expected to reduce the water channelling and improve the oil recovery factor. Therefore, the confirmation in residual oil recovery was confirmed by core flooding experiments.



a) Surfactant – Crude oil instant mixing

b) Surfactant – Crude oil after 24 hours

c) Surfactant – Crude oil – Nanoparticles after 24 hours

Figure 2. The emulsion formation using crude oil and different surfactants (a), and its stability observation without nanoparticles (b) and with nanoparticles (c).

3.2 Core flooding oil recovery

The oil recovery obtained by core flooding experiments using sandpack is formulated in Table 2. The porosity of the sandpack were close to 30% with permeability approximately 1800 mD. The oil saturation was more than 80% in each run of the core flooding experiment. The data showed that oil recovery with secondary water flooding was almost 30% of the original oil in place (OOIP). Moreover, with surfactant flooding for which high emulsion were observed (TX-100), a recovery of around 19% were accomplished. The recovery was enhanced to 24% for nanofluid solutions (TX-100 and SiO_2 nanoparticles mixture) and this was due to the higher emulsion stability that improves the residual oil displacement efficiency.

Table 2. Sandpack core flooding data representing oil recoveries using TX-100 surfactant (emulsion) and 0.25 wt% TX-100 + 0.1 wt% SiO_2 nanoparticles (nano-emulsion)

Sr. No.	**Porosity (%)**	**Permeability (mD)**	**Initial Oil Saturation (%)**	**Surfactant/ Nanofluid**	**Water Flooding (%)**	**Oil Recovery (%)**
1	30.4	1845	82.4	Emulsion	30.2	18.8
2	28.9	1722	81.8	Nano-emulsion	29.3	24.2

4. Conclusion

The current work compares and demonstrate the potential of emulsion induced by surfactant and nano-emulsion formed using surfactant – nanoparticle towards oil recovery factor. The outcomes accomplished from the study are as follows:

1. The selected surfactants (SDS, SDBS, AOS and TX-100) were able to formed emulsions with the crude oil belonging to light to moderate category.
2. Surfactant Triton X-100 showed better interaction with the crude oil to produce stable emulsion as compared to the other three surfactants.
3. Nanofluid solution prepared by deploying SiO_2 nanoparticles in Triton X-100 solution, showed promising emulsion stability as compared to normal emulsion formed by Triton X-100.
4. Finally, the core flooding studies confirmed the potential of nano-emulsion by producing 24% additional oil recovery as compare to 19% oil recovery achieved by Triton X-100 (surfactant) only.

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Biography

Dr. Rahul Saha is working as an Assistant Professor in the Department of Chemical Engineering at National Institute of Technology Hamirpur, Himachal Pradesh, India. He received his Ph.D. degree in Chemical Engineering from Indian Institute of Technology Guwahati, India (2019). His research is focused on Chemical Enhanced Oil Recovery, Colloids & Interface Science, Nanotechnology in Oil and Gas, Nanofoam, Flow through Porous Media, Rheology, Adsorption Kinetics, and Biodiesel. So far, he has published several research articles in internationally reputed journals, 1 book, numerous book chapters, and has reviewed numerous technical articles.