Foam stability using silica coated nanoparticle for enhanced oil recovery

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Abstract. A mixture of nanoparticles and water can be used in the nano-water alternating gas approach (NWAG) to enhance oil recovery from an oil field. Now, the wettability of rock, relative permeability curves, and the interfacial tension analyzed for improvement of the operation. With an approach application, nanoparticles became importance over the last decade but the activity of using nanoparticles is practically unknown. A major stumbling-block to the success of foam application in EOR is the adverse influence of oil on foam stability. The objectives were to evaluate the effects of various surfactant, nanoparticle concentration as well as hydrocarbons with well-defined properties on foam stability. Orderly, a comprehensive series of experiments at static state is conducted to investigate the foam stability of five different concentrations for surfactant and nanoparticle respectively in the absence and presence of mineral oil and synthetic brine suspension. The results suggested that there is a significant impact of the concentration of the surfactant and nanoparticle on foam stability. Besides, results suggested that less stable foam is shown in the presence of oil as compare to brine solution. The addition of half life method shows the promising result on the use of nanoparticles as foam stabilizer.

1. Introduction
Enhanced oil recovery (EOR) is the pioneering applications of foam. A key stumbling block to the aim of foam application in EOR is the adverse influence of oil on foam stability. The purpose of the research to define the characteristic on foam stability using various surfactants and hydrocarbons. By doing that, I managed a series of experiments at bulk and bubble-scale to look for the foam stability of surfactants in the lack and exist of iso-paraffins well known by their viscosity, and density. For bulk foam stability experiments, it was generated by let the surfactant solution expose to the pure air. Observe the decay of foam time to time by using automated camera to record it. The significant impact type of surfactant on foam stability is shown as the results. Moreover, the foam unstable in the presence of oil with less disadvantages on foam stability because oil density and viscosity increased. The constraint of procedure used in the present study to analyze foam stability, i.e., foam height is measured over by time to time. Moreover, it is one of
the way approach is proposed to observe foam stability at bubble-scale to supplement and improve understanding of the physical phenomena manage foam stability.

In view the fact that foams have been utilizing in well-nigh every level of the petroleum production as well as refining process, begin with fathomless producing reservoirs, following by oil well drilling, stimulation, and production, till downstream vessels, foam stability factor has been accentuated in the field involved [1-4] According to [5] foam generated by surfactant are prompt to be insufficient for mountainous scale operation like enhanced oil recovery (EOR) as they are almost inclined to worsen chemically in the beginning even before executing their purpose. The inability of this foam to maintain long-term stability occur especially at elevated temperature or with the presence of oil or brine. The objective of tertiary recovery to repossess oil that left in reservoirs after first and second recoup methods which the process that diminishes the residual oil saturation by gas and/or chemical injection, as well as thermal recovery methods [8]. Although, the high mobility ratio between the displacing gas phase and the displaced oil phase is a critical challenge encountered in the EOR process. In other meaning, such low-viscosity gas is more volatile than displaced oil or water in the reservoir.

Titanium oxide coated nanoparticles (TiO C-Nps) with a polyelectrolyte to stabilize oil in water emulsion. Recently, at lower polymer chain grafting densities is the most stable emulsion were formed and the stability of oil mix with water emulsion in using of silica coated nanoparticles with a pH responsive polymer. According on polymers’ star study, bottlebrush polymers, and paramagnetic particles with adsorbed amphiphilic polymers discovered stable emulsions and decreases in the oil-water interfacial pressure at moderately low (0.1wt %) molecule substance. The dynamic decrease in interfacial pressure of air and water within the sight of C-NPs while changing the uniting thickness of the polymer brushes and demonstrated that the polymer covering is a key factor in lessening the interfacial strain of air and water utilizing C-NPs. C-NPs with improvements responsive polymer chains have additionally been accounted for. C-NPs can react to temperature, pH, and light through an adjustment in surface properties. Improvements responsive C-NPs can possibly be utilized to structure injectable liquids that react to natural changes when infusion or within the sight of oil.

2. Material and methods

2.1. Materials

All chemicals and reagents which are 99% purity of sodium dodecyl sulfate, brine solution, and white mineral oil will be obtained from University Malaysia Pahang Chemical and Process Engineering Technology Laboratory. All chemicals are analytical grade. Titanium oxide coated nanoparticles can be obtained from University Technology PETRONAS (UTP).

2.2. Preparation of coated nanoparticle, C-NP (Titanium oxide) –surfactant (SDS) aqueous dispersion

0.5 wt% of surfactant will be dispersed in the deionized water of known volume. The solution is shaken for two hours by using Orbital Shaker at 240 rpm until a homogenous solution was obtained. Then, coated nanoparticle will be added to the solution. Brine and white mineral oil are added if necessary. To obtain adsorption equilibrium the dispersion is ultra-sonicated for 4 h. The magnetic stirring helps to disperse the coated nanopowders evenly in the base fluid, but the energy is not enough to break any agglomeration of coated nanoparticles. So an ultrasonic bath is used to break the agglomerations of coated nanoparticles. The nonionic surfactant is not sensitive to salinity variations because it largely relies on steric repulsive force to disperse the coated nanoparticle. This is desirable to select nonionic surfactants as good candidates, especially for high salinity conditions. The hydrophobic tail of the nonionic surfactant sodium dodecyl sulphate (SDS) is non-covalently adsorbed onto the C-NP’s surface, while the hydrophilic head provides strong steric repulsion to prevent aggregation and improve dispersiveness of C-NPs.
2.3. Static bulk foam test

The strength of mass foam can be examined from numerous points of view [11][15]. Mass foam trials can be static or dynamic. The security test is arranged and altered dependent on ASTM-D 6082-62 [1]. In this investigation, the security of the fluid foam was assessed by alluding to the Ross-Miles technique, utilizing half-life estimations. At that point, by estimating the time required for the froth to deplete one portion of the underlying volume arrangement it will acquire the half-life. The method utilized in the age of froth is air development. This system is utilized to assess the solidness of froths in nearness of nanoparticles, surfactant, salt water and white mineral oil. 1 L graduated chamber, circular gas diffuser stone made of melded crystalline alumina grain, stream meter, valve, and high immaculateness carbon dioxide tank is comprised in the gear. A standard volume of arranged arrangement is brought into the barrel. Now, carbon dioxide (CO₂) is permitted to course through the cylinder into the base of the arrangement. The CO₂ streamed upward through a gas diffuser at the lower end of the chamber. Contingent upon the viability of nanoparticles, the air pockets either framed a layer of froth like scattering at the highest point of the chamber or mixed into a reasonable layer of CO₂ gas. The stream meter will be shut and the security of froth controlled by estimating the froth layer thickness versus time after the standard volume of CO₂ (500 mL/min) is presented.

Additionally, as to characterize the foam stability, normalized foams height were measured and calculated by using Equation 1:

\[
\text{Normalized height} = \frac{\text{foam height (t)}}{\text{foam height (t=0)}}
\]

(1)

where; t = time [8].

2.4. Half life test

So as to decide the basic foaming specialist focus to be blended with water Half-life tests for the foaming operators will be directed. Surfactant and nanoparticle is to be blended with water by various focuses (SDS: 0.05wt%, 0.1wt%, 0.15wt%, 0.2wt% and 0.25wt%; C-NPs: 0wt%, 0.1wt%, 0.3wt%, 0.5wt% and 1.0wt%) and stirred by methods for an Orbital Shaker, and afterward moved into a graduated chamber. Introductory complete foam volume is estimated and recorded. At that point, the volume of fluid stage gathered at the base of the graduated chamber is estimated and recorded as an element of time. The season of this period is recorded as the half-existence of the froth when half of the all-out fluid volume depleted at the base of the graduated barrel.

The method [2] is based on the measurement of the liquid phase drained volume as a function of time. Foams are to be prepared through stirring at 5200 Rpm of 100 ml of the liquid phase during 60 seconds in a blender. The prepared foam is immediately transferred to a 1000ml graduated cylinder and the drained
the liquid at the bottom of the graduated cylinder is recorded every 15 seconds, in the range of 15-300 seconds. Besides this, as half of the total liquid phase has been drained the time is to be registered as half-life for this surfactant. Below are shown three equivalent formulas describing exponential decay:

\[ H(t) = H_0 \left( \frac{t}{t_{1/2}} \right)^{1/2} \]  
(2)

\[ H(t) = H_0 e^{-\frac{t}{\tau}} \]  
(3)

\[ H(t) = H_0 e^{-\lambda t} \]  
(4)

where, \( H_o \) is initial foam height, \( H_t \) is remaining foam height after time, \( t, t_{1/2} \) half-life, \( \tau \) mean lifetime and \( \lambda \) is decay constant [2].

2.5. Viscosity test
In this study, four potential formulations examined by stability tests were further assessed their viscosity property. For comparison, the viscosities of these formulations in absence of C-NPs were also examined. A low viscosity rotational type viscometer will be used to measure viscosity characteristic of C-NPs based nanofluids and particle-free aqueous solutions. The viscosity of pure distilled water was measured prior to experiments for nanofluid samples in order to verify the accuracy of the instrument. The result is compared with that from the literature. Measurements were taken at several shear rates at 25°C.

3. Results and discussions
A total of 5 different concentrations for surfactant and coated-nanoparticle (titanium oxide coated nanoparticle) were prepared for the experiments. The static bulk foam analysis and half-life test is presented first, followed by individual testing results and discussions presented in subsections. In all experiments, uncertainty is a norm and are essential for the reliability of the experimental task. Conflict related to the experiments conducted in this study can be categorized into two part which includes experimental and equipment uncertainties. The overall uncertainty in an experiment is the total of errors related to the many steps in preparing the experiment, and the uncertainties in the equipment. The main contributor related to the errors in this study is the experimental uncertainty. This uncertainty is hard to control, and is related to gas leakage, temperature variations and others.

3.1. Surfactants foam stability
3.1.1. Static bulk Test. In this experiment, after the granulated cylinder was filled for 10 minutes, the CO\(_2\) gas sparging into the cylindrical foam column was terminated. Then foam height reduction was monitored over time for 10 minutes. In the static bulk experiments, the half-decay time which is defined as the time taken to attain half of the initial height of the foam was used as the criterion to quantify foam stability, whereby, the higher the half-decay time the more stable the foam produced and vice versa. This criterion was referred according the studies previously conducted by [9][10]. The concentration of SDS surfactant is crucial to foam stability and, based on these results below, whereby, stronger foam can be produced using 0.25 wt% of SDS surfactant for both condition. Optimum behaviors were observed at 0.25 wt% SDS surfactant. Relative foam height measurements (normalized height), 0.25 wt% SDS surfactant produces more stable foams at both absence and presence of white oil with normalized height of 0.5 and 0.42 respectively. For the weakest foam produce is 0.05 wt% of SDS surfactant is the lowest normalized height obtained from the experiment which are 0.36 in absence of white oil and 0.3 in the presence of white oil.
Figure 2. (a) Foam life for brine solution and mixture of 0.05 wt%, 0.1 wt%, 0.15 wt%, 0.2 wt% and 0.25 wt% SDS surfactant in absence of white oil. (b) Foam life for brine solution and mixture of 0.05 wt%, 0.1 wt%, 0.15 wt%, 0.2 wt% and 0.25 wt% SDS surfactant in presence of white oil.

SDS foam was characterized by broad bubbles size distribution and a fairly uniform bubble size distribution. Soon after the end of gas sparging, the foam column entered the decay regime. This is consistent with a very short t1/2 for SDS foam in presence of white oil. The SDS surfactant created stable foam, carrying almost all the initial oil upward, and leading to a fairly uniform oil distribution in the top of the column.

3.1.2 Half-life Test. The results portrayed in Figure 10 showed that 0.25 wt% concentration of SDS foam creates the most stable foam with the half-decay time of 10 min while the weakest fell on the 0.05 wt% concentration of SDS foam which held the position of lowest stability with the half-decay time of 6.83 min in the absence of oil. The surfactant concentration can be ranked in terms of their t1/2 in both condition as follows: 0.25 wt% > 0.2 wt% > 0.1 wt% > 0.15 wt% > 0.05 wt%.

Figure 3. Effect of different wt% of SDS surfactant concentration on foam stability in term of half-life in absence and presence white oil.
3.2. Silica coated nanoparticle (Titanium Oxide) foam stability

3.2.1. Static bulk test. The most preferable concentration of surfactant with the ability to sustain the foam stability for the longest time was chosen through the experiment for surfactant screening. The result had shown that 0.25 wt% of SDS surfactant served as a better wetting agent that increases the stability of the foam for both condition, whether it’s in absence or presence of oil with the highest half-life and normalized height. In consequence, 0.25 wt% of SDS concentration is use in this test which is to analyse the foam behaviour using variation of concentration of titanium oxide coated nanoparticle in the presence and absence of oil through the same testing used in surfactant foam stability tests. Each titanium coated nanoparticle concentration of 0.0 wt%, 0.1 wt%, 0.3 wt%, 0.5 wt% and 1.0 wt% titanium coated nanoparticle concentration mixtures in brine solution either in presence or absence of white oil.

The concentration of coated nanoparticle (C-Nps) is crucial to foam stability and, based on these results, whereby, stronger foam can be produced using nanoparticle for both condition. Optimum behaviours were observed at 0.5 wt% titanium oxide C-Nps in absence of white oil and also 0.5 wt% of titanium oxide C-Nps in presence of white oil. However the case, as the concentration of nanoparticle exceed a certain amount, the stability of foam as well as the oil displacing efficiency dropped dramatically as portrayed by 1.0 wt% of titanium oxide C-Nps in both condition but it is not become the weakest yet. If the experiment is undergo with higher titanium oxide C-Nps concentrations, it might become the weakest stability.

![Figure 4](image1.png) (a) Foam life for 0.25 wt% SDS in brine solution and mixture with 0.0 wt%, 0.1 wt%, 0.3 wt%, 0.5 wt% and 1.0 wt% titanium oxide C-Nps in absence of white oil. (b) Foam life for 0.25 wt% SDS in brine solution and mixture with 0.0 wt%, 0.1 wt%, 0.3 wt%, 0.5 wt% and 1.0 wt% titanium oxide C-Nps in presence of white oil.

3.2.2. Half-life Test. Figure 5 shows the drainage curves for the TiO-SDS-stabilized foam in the absence and presence of white oil in term of half-life. The drainage of the foam was the fastest in the presence of white oil and the slowest in absence of white oil. In the absence of oil, the 0.5 wt% of titanium oxide C-Nps exhibited the most stable foam with a t_{1/2} longer than 20 min and 12.97 min in presence of white oil. The weakest is portrayed to 0.0 wt% for both condition which is 10 min in absence of white oil and 7.98 min for presence of white oil. The coated nanoparticle concentration can be ranked in terms of their t_{1/2} in absence of white oil as follows: 0.5 wt% > 0.3 wt% > 1.0 wt% > 0.1 wt% > 0.0 wt% while in terms of their t_{1/2} in presence of white oil as follows: 0.5 wt% > 0.3 wt% > 0.1 wt% > 1.0 wt% > 0.0 wt%.
3.2.3. Viscosity test. In Table 1, viscosity of SDS in brine solution dropped then increased obviously as the SDS concentration increases. On the other hand, the viscosity of coated nanoparticle-surfactant in brine solution showed a drastic drop for the concentration from 0 wt% to 0.1 wt% then increased steadily as the TiO coated nanoparticle concentration increases (Table 2). This showed that, on the one hand, the higher coated nanoparticle concentration results in a more viscous liquid phase and the drainage rate of bulk foam can be more easily retarded, which improves the foam stability.

**Table 1.** Viscosity of SDS in absence of oil and presence of oil with vary concentration.

| SDS in brine | SDS in oil |
|--------------|------------|
| 0.05 wt%     | 0.05 wt%   |
| 0.1 wt%      | 0.1 wt%    |
| 0.15 wt%     | 0.15 wt%   |
| 0.2 wt%      | 0.2 wt%    |
| 0.25 wt%     | 0.25 wt%   |
| 0.5 wt%      | 0.5 wt%    |
| 1.0 wt%      | 1.0 wt%    |
| Viscosity    | Viscosity |
| 4.1          | 6.5        |
| 3.3          | 5.5        |
| 3            | 4.3        |
| 3.6          | 2.9        |
| 4.5          | 3.9        |
| 2.2          | 2.6        |
| 2.5          | 3.1        |
| 3            | 2.9        |
| 2.6          | 2.6        |

**Table 2.** Viscosity of C-Nps SDS surfactant mixture in absence and presence of oil with vary concentration.

| C-Nps in brine | C-Nps in oil |
|----------------|--------------|
| 0.0wt%         | 0.0wt%       |
| 0.1wt%         | 0.1wt%       |
| 0.3wt%         | 0.3wt%       |
| 0.5wt%         | 0.5wt%       |
| 1.0wt%         | 1.0wt%       |
| 0.0wt%         | 0.0wt%       |
| 0.1wt%         | 0.1wt%       |
| 0.3wt%         | 0.3wt%       |
| 0.5wt%         | 0.5wt%       |
| Viscosity      | Viscosity    |
| 4.5            | 2.1          |
| 2.2            | 3.1          |
| 2.5            | 2.9          |
| 3              | 2.6          |
| 2.6            | 3.9          |
| 3              | 3.1          |
| 2.6            | 2.9          |
| 2.5            | 2.6          |

3.2.4. Characterization of the synthesized TiO coated nanoparticles. Figure 6 presents the spectra of the TiO coated nanoparticle mixture in 0.25%wt SDS and brine solution before gas sparging in which organic bonding can be detected in the range of 400 cm\(^{-1}\) - 4000 cm\(^{-1}\). With adding coated nanoparticle into the surfactant and brine suspension, these bonding vibrations gradually increases with more spikes even if these peaks are small in consideration to the alcohol bond, O-H and alkyne bond, C≡C. The FTIR spectrum reveals a significantly broad band at an approximate range from 3600 cm\(^{-1}\) and 3000 cm\(^{-1}\) that correspond to the bending vibrations of the amide bands of the coated nanoparticle. In the approximate range from 1500 cm\(^{-1}\) to 500 cm\(^{-1}\) and 3500 cm\(^{-1}\) to 3000 cm\(^{-1}\), C=O and Ti=O bending and stretching vibrations due to the polyethylene oxide (PEO) of surfactant SDS and TiO coated nanoparticles can be observed. Strong
absorptions at 1085 cm$^{-1}$ and 800 cm$^{-1}$ also can be observed. These absorptions identified respectively as the Ti-O-Ti asymmetry and symmetry bands.

![Figure 6: FTIR spectra of the TiO coated nanoparticles in 0.25 wt% of SDS and brine solution at 0 wt%, 0.1 wt%, 0.3 wt%, 0.5 wt% and 1.0 wt%. [Transmittance].](image)

The adsorption increase gradually with C-Nps concentration with the amount minor peaks increased. Adsorption with respect of number of peaks starts to increase rapidly at starting from 0.1 wt% of C-Nps, almost all the different concentration showed the same pattern obtained at lower C-Nps particles but still absorbed the highest numbers of SDS monomers. A reasonable explanation of these behaviours can be concluded; at low TiO coated nanoparticles concentration, less surface contact area between solution and the particles take places and thus few amount of surfactants are being absorbed and the versa happened at higher TiO coated nanoparticles concentration. Surfactant adsorbed on C-Nps surface are mainly governed by the initial interaction between silica surface and ethylene oxide head groups [13 - 15].

4. Conclusion

Foam characteristics were studied at different surfactants and coated nanoparticle concentrations in absence and presence of white oil. Foamability and foam stability enhances as surfactants and coated nanoparticle concentrations increases. Other than that, High concentration solutions were characterized by fine and fairly uniform distributed bubble size whereas lower concentrations clearly reveals a different foam texture with larger bubble sizes and broad distribution. The addition of nanoparticles at certain concentration to this specific synthetic saltwater and oil shows promise when it comes to increasing the half time of foam as it might help to slow the drainage of thin aqueous film and, therefore, to produce a more stable foam. The 0.5 wt% TiO coated nanoparticles foam formed the most stable in the absence of oil and was largely influenced by the oil phase as its $t_{1/2}$ in presence of oil is smaller than that in absence of oil. Overall, the results with
added coated nanoparticles are better than the results with no added coated nanoparticles in term of foam stability. Thus, nanotechnology has the potential to have a positive effect on the chemical EOR process.

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