FOAM STABILIZATION AND WETTABILITY ALTERATION IN A SURFACTANT-CARBON DIOXIDE FOAM FLOODING BY USING SILICON DIOXIDE NANOPARTICLES

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ABSTRACT

Previous studies of nanoparticles stabilized surfactant foam flooding are mainly conducted in the water-wet porous media. Hence, the purpose of this study is to investigate the foam stabilization in the oil-wet system since the applied surfactant and nanoparticles also show an effective function as wettability modifier agents. The effect of surfactant concentration beyond the critical micelle concentration (CMC) was studied during the foam static test and wettability alteration test. The static foam tests conducted were half-life, bubble size distribution, mean diameter, and lamella thickness; while the dynamic tests conducted were pressure drop, foam apparent viscosity, mobility reduction factor, oil recovery, and the effect of heterogeneity. The wettability alteration was measured by using the contact angle method. This study also investigated surfactant adsorption on clay in the presence of nanoparticles. The result shows that, the presence of nanoparticles significantly enhanced the surfactant foam in the static test where the most influential parameter was particle hydrophobicity. At CMC, the half-life of cetyltrimethylammonium bromide (CTAB) and sodium dodecyl sulfate (SDS) foam increased from 491 s and 700 s to 1360 s and 4089 s, respectively in the presence of partially hydrophobic silicon dioxide (PH SiO_2) nanoparticles. In the wettability alteration test, the type of surfactant and nanoparticles which produced the lowest contact angle was an inverse sequence of the foam static test. The contact angle of the carbonate rock was reduced from 112.00° to 28.35° by using CTAB and hydrophilic SiO_2. The effect of surfactant concentration beyond the CMC also shows an inverse effect between the foam static test and wettability alteration test. The effect of nanoparticles in reducing surfactant adsorption on clay was governed by particle hydrophobicity. During the dynamic test, the oil recovery of CTAB and SDS foam flooding increased from 62.07% and 66.36% to 67.03% and 71.79%, respectively in the presence of PH SiO_2. Besides, the oil recovery in the heterogeneous oil-wet glass bead pack was higher from the high-permeability layer than the low-permeability layer. In conclusion, PH SiO_2 nanoparticles have successfully stabilized surfactant foam in an oil-wet system. This suggests that the same nanoparticles could be utilized in the current foam enhanced oil recovery application worldwide, especially in the carbonate reservoirs.

ABSTRAK

Kajian-kajian terdahulu tentang penstabilan banjiran busa surfaktan oleh partikel nano kebanyakannya dijalankan di dalam media poros yang bersifat basah-air. Maka, tujuan kajian ini adalah untuk mengkaji kestabilan busa di dalam basah-minyak memandangkan surfaktan dan partikel nano yang digunakan juga efektif sebagai agen pengubah kebasahan. Kesan kepekatan surfaktan yang melebihi kepekatan kritikal penggumpalan (CMC) telah dikaji ketika ujian statik busa dan pengubahan kebasahan. Ujian statik busa yang dibuat adalah separa-hayat, taburan saiz busa, purata diameter, dan ketebalan lamela; manakala ujian dinamik yang dibuat adalah pengurangan tekanan, kelikatan busa, faktor pengurangan mobiliti, penghasilan minyak, dan kesan ketidakseragaman lapisan. Perubahan kebasahan diukur menggunakan kaedah sudut sentuh. Kajian ini juga mengkaji penjerapan surfaktan di atas permukaan tanah liat dengan kehadiran partikel nano. Hasil kajian menunjukkan partikel nano berkesan bagi meningkatkan busa surfaktan ketika ujian statik di mana parameter utama yang mempengaruhi adalah hidrofobik partikel. Separa-hayat busa cetiltrimetilammonium bromida (CTAB) dan sodium dodesil sulfat (SDS) ketika CMC masing-masing meningkat dari 491 s dan 700 s kepada 1360 s dan 4089 s dengan kehadiran partikel nano separa-hidrofobik silikon dioksida (PH SiO_2). Ketika ujian pengubahan kebasahan, jenis surfaktan dan partikel nano yang menghasilkan sudut sentuh terkecil menunjukkan penyongsangan turutan berbanding ujian statik busa. Sudut sentuh batu karbonat telah dikurangkan dari 112.00^o kepada 28.35^o oleh CTAB dan SiO_2 hidrofilik. Kesan kepekatan surfaktan yang melebihi CMC juga menunjukkan penyongsangan di antara ujian statik busa dan ujian pengubahan kebasahan. Pengurangan penjerapan surfaktan di atas permukaan tanah liat oleh partikel nano dipengaruhi oleh hidrofobik partikel. Ketika ujian dinamik, penghasilan minyak oleh busa CTAB dan SDS masing-masing meningkat dari 62.07% dan 66.36% kepada 67.03% dan 71.79% oleh PH SiO_2. Juga, penghasilan minyak di dalam pek manik kaca basah-minyak dari lapisan kebolehtelapan tinggi melebihi lapisan kebolehtelapan rendah. Kesimpulannya, busa surfaktan telah distabilkan oleh PH SiO_2 di dalam sistem basah-minyak. Adalah diharapkan partikel nano tersebut dapat digunakan di dalam busa bagi meningkatkan perolehan minyak tertingkat semasa dunia terutamanya di reserbor karbonat.

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LIST OF ABBREVIATIONS

AI	-	Adsorption Index
AOS	-	Alpha Olefin Sulfonate
CMC	-	Critical Micelle Concentration
CSC	-	Critical Salt Concentration
CTAB	-	Cetyltrimethylammonium Bromide
DFA	-	Digital Foam Analyzer
EDX	-	Energy-Dispersive X-ray
EOR	-	Enhanced Oil Recovery
FAWAG	-	Foam Assisted Water Alternating Gas
GOR	-	Gas-to-Oil Ratio
HLPN	-	Hydrophobic and Lipophilic Polysilicon Nanoparticles
IFT	-	Interfacial Tension
IOR	-	Improved Oil Recovery
LHPN	-	Lipophobic and Hydrophilic Polysilicon Nanoparticles
Mb/d	-	Million barrel per day
MRF	-	Mobility Reduction Factor
NaCl	-	Sodium Chloride
NFCR	-	Naturally Fractured Carbonate Reservoir
NWPN	-	Neutrally Wet Polysilicon Nanoparticles
OOIP	-	Original Oil In Place
PEG	-	Polyethylene Glycol
PH SiO_2	-	Partially Hydrophobic SiO_2
PV	-	Pore Volume
pzc	-	Point zero charge
SAG	-	Surfactant Alternating Gas
SD	-	Standard Deviation
SDS	-	Sodium Dodecyl Sulfate
SEM	-	Scanning Electron Microscopy
TTAB	-	Trimethyltetradecylammonium Bromide
WAG	-	Water Alternating Gas

LIST OF SYMBOLS

ΔCMC - Changes of CMC
Θ - Contact angle
λ_{NPS} - Conductivity of nanoparticles
λ_{S} - Conductivity of surfactant
ρ - Density
ΔP - Difference of pressure
ΔW - Difference of weight
μ_{app} - Foam apparent viscosity
π - Pi
$\varnothing$ - Porosity
γ - Surface tension
$\sigma_{g\text{-}l}$ - Surface tension of gas-liquid
$\sigma_{g\text{-}s}$ - Surface tension of gas-solid
$\sigma_{s\text{-}l}$ - Surface tension of solid-liquid
μ - Viscosity
A - Cross sectional area
d - Diameter
D - Diffusion coefficient
E - Energy
h - Height
k - Permeability
k_{B} - Boltzman constant
k_{rg} - Relative permeability of gas
k_{ro} - Relative permeability of oil
k_{rw} - Relative permeability of water
l - Length
p^{c}_{max} - Maximum capillary pressure
Q_{b} - Foam quality
q - Flow rate
r - Radius

S_{oi} - Initial oil saturation

S_{or} - Residual oil saturation

$\mathrm{S}_{\mathrm{wir}}$ - Irreducible water saturation

T - Absolute temperature

T_c - Cloud temperature

V_{bulk} - Bulk volume

V_g - Volume of gas

V_L - Volume of liquid

V_t - Volume of 100% water saturation

V_w - Volume of water displaced by oil

$W1$ - Weight of dry glass bead pack

$W2$ - Weight of 100% water saturated glass bead pack

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

International Energy Agency (2018) estimated that world oil demand could growth from 97.8 million barrels per day (mb/d) in 2018 to 104.7 mb/d in 2023, with an annual average growth rate of 1.38 mb/d. Due to most of the world oil production is produced from mature fields, hence, the optimal method to increase the oil recovery from mature fields is the main concern by major oil and gas companies (Alvarado & Manrique, 2010). On the other hand, due to economic constraints, it becomes harder to discover new oil wells to substitute the produced reserves, especially in a declining oil price regime. As a result, major oil companies are preferred in utilizing improved oil recovery (IOR) and enhanced oil recovery (EOR) methods to achieve energy demands. Consequently, gas flooding, thermal flooding, and chemical flooding are the three primary techniques of worldwide EOR (Alvarado & Manrique, 2010).

In 2018, it was estimated that around 375 EOR projects operating globally, which supply 2% of global oil production by producing over 2 mb/d (McGlade et al., 2018). As shown in Figure 1.1, CO_2-EOR becomes the largest number of EOR projects globally since 2006 after surpassed thermal flooding. Besides, CO_2 flooding is envisioned to become even more popular in the future due to natural CO_2 source availability and possible large anthropogenic CO_2 sources through carbon capture and storage technology advances (Enick et al., 2012). The cheap sources of CO_2 from natural sources (USD 1–2/Mscf) and a ready pipeline system making CO_2 flooding economically attractive at oil prices of USD 20 per barrel (Manrique et al., 2007).

Either miscible or immiscible, CO_2 flooding improves oil recovery by several mechanisms-e.g., promotes oil swelling, reduces oil viscosity, exerts an acidic effect on rock, and vaporizes and extracts portions of crude oil (Sheng, 2011; Enick et al., 2012; Farajzadeh et al., 2012).

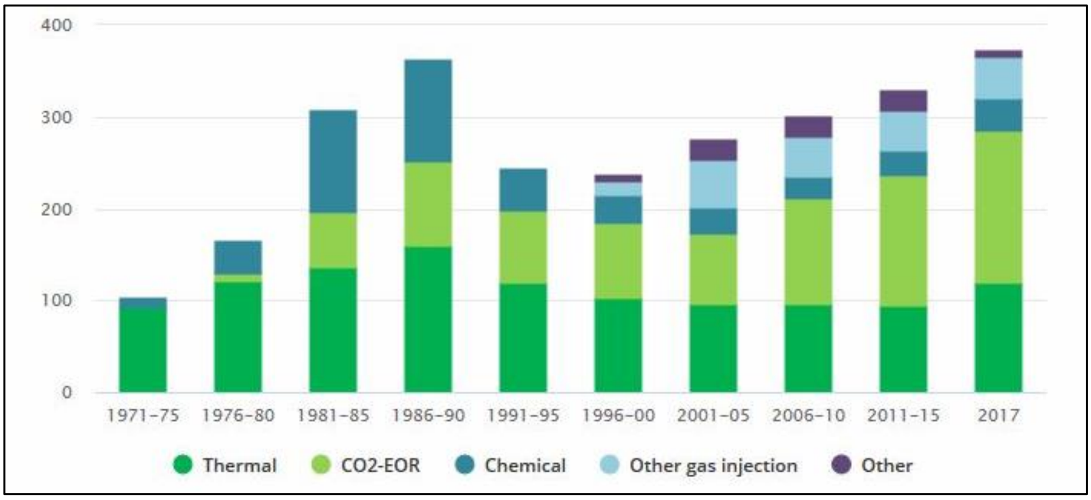

Figure 1.1 Number of EOR projects globally (McGlade et al., 2018)

However, the fundamental problem which limiting the full potential of CO_2 flooding is inherently poor sweep efficiency, especially in heterogeneity reservoir or fractured formation where large permeability difference is in capillary contact (Haugen et al., 2012). The low density of high-pressure CO_2, e.g., 0.4953 g/cm^3 at 66 ^oC and 2030 psia (Anwar & Carroll, 2016) relative to oil promotes gravity override of the CO_2, reducing oil recovery in the lower portions of the formation. Besides, the low viscosity of CO_2, e.g., 0.03618 cP at 66 ^oC and 2030 psia (Fenghour et al., 1998) compared to oil which is hundreds or thousands times bigger further hampered CO_2 flooding because it leads to viscous fingering, early gas breakthrough and high gas-to-oil ratio (GOR). Miscible CO_2 flooding typically recovers 10–20% of original oil in place (OOIP), while immiscible CO_2 flooding only recovers 5–10% of OOIP (Enick et al., 2012).

Technically, the sweep efficiency of CO_2 flooding can be improved by three methods: water alternating gas (WAG), thickener, and foam (Enick et al., 2012). Contemporary, WAG flooding (either miscible or immiscible) has been more implemented in the current worldwide oil field rather than thickener or foam. Despite water stabilizes the front which reduces gas mobility, the WAG method is strongly influenced by the reservoir stratification layer, heterogeneity effect, and still inhibits by viscous-gravity ratio, which reduce its effectiveness in improving sweep efficiency (Talebian et al., 2018). Besides, as the WAG process continues inside reservoir, the excesses of the injected water may hinder the gas from contacting the oil. The WAG also not suitable to be applied in a tight and water-sensitive reservoir, where the continuous injection of CO_2 is more appropriate (Enick et al., 2012).

On the other hand, CO_2-polymer thickener which enhances gas viscosity is difficult to be developed because of low CO_2 solubility during intermolecular associations (Enick et al., 2012). Affordable polymer thickener also remains a challenge, whereas foam has been proven to be the low-cost alternative in difficult reservoir conditions such as very low permeability and high temperature (Li et al., 2008; Srivastava & Nguyen, 2010). Considering the limitation of WAG and thickener, thus, foam is regarded as a promising EOR in improving gas sweep efficiency.

In general, foam flooding can improve oil recovery in three ways compared to gas or WAG flooding (Farajzadeh et al, 2010; Sun et al., 2014):

i. By stabilizing the displacement process by increasing the viscosity of displacing fluid.
ii. By blocking the higher permeable swept zones and diverting the fluid into lower permeable unswept zones.
iii. By reducing the capillary forces by reducing the interfacial tension (IFT) of rock-fluid in the presence of surfactant.

Foam stability and its propagation inside reservoir are crucial factors for successful foam flooding. Several approaches have been conducted on how to stabilize the generated foam by adding some sort of additive. Usually, surfactant is regarded as the most common foam stabilizing agent (Bureiko et al., 2015; Langevin, 2017; Memon et al., 2017). Besides, polymer (Petkova et al., 2012; Telmadarreie & Trivedi, 2018) and protein (Saint-Jalmes et al., 2005; Samin et al., 2017) are also recognized as conventional foam stabilizing agents. However, the generated foam by an individual surfactant, polymer, and protein, or combination of them are unable to maintain their stability in a longer period time, resulted of their low adsorption energy at gas-liquid interfaces (Wang et al., 2015; Srivastava et al., 2017).

On the other hand, the development of nanotechnology has paved the way for using nanoparticles as a foam stabilizer. Nevertheless, since nanoparticles do not reduce the surface tension significantly, it is difficult to generate foam in the absence of surfactant (Kostakis et al., 2007; Karaskashev et al., 2011; Sun et al., 2015; Farhadi et al., 2016). The presence of nanoparticles significantly increases foam stability, foam apparent viscosity, lamella thickness, and oil recovery compared to surfactant foam (Sun et al., 2014; Babamahmoudi & Riahi, 2018; Maurya & Mandal, 2018).

The significant difference between nanoparticles and surfactant as foam stabilizer is the adsorption energy of nanoparticles at gas-liquid interfaces, which is thousands times bigger than surfactant adsorption energy. Besides, surfactant adsorption is reversible but conversely irreversible adsorption for nanoparticles. According to the adsorption energy equation, the influenced parameters are particle size, the surface tension of gas-liquid, and particle hydrophobicity (Binks, 2002; Aroonsri et al., 2013; Farhadi et al., 2016).

Surfactant concentration plays a major role in nanoparticles stabilize surfactant foam flooding. It is generally accepted that during surfactant foam flooding, surfactant concentration at critical micelle concentration (CMC) shows the optimum effect on foam stability. Nevertheless, it should be noted that the CMC of surfactant reduces with increasing brine salinity (Schramm & Wassmuth, 1994; Holmberg et al., 2002; Wang et al., 2016). Thus, during nanoparticles stabilize surfactant foam flooding, the excess of surfactant concentration which beyond the CMC, or maintaining the CMC in deionized water to saline water will have an inverse effect on particle hydrophobicity, which induces the nanoparticles to be hydrophilic back (Binks & Rodrigues, 2007; Sun et al., 2015; Farhadi et al., 2016; Li et al., 2017). As a result, the adsorption energy of nanoparticles on gas-liquid interfaces will decrease.

The stability of foam inside porous media is also sensitive to the wettability of the rock, where the oil-wet system has a detrimental effect on foam stability (Li, 2011; Skauge et al., 2019). Despite foam could be formed and propagated in intermediate-wet and oil-wet system in the presence of oil, the produced foam was unstable and about 1.5 times lower mobility reduction factor (MRF) compared to the water-wet system except for a few cases where the surfactant reversed the wettability towards water-wet (Schramm & Mannhardt, 1996).

On the other hand, the newly explored discipline in wettability alteration is by utilizing nanoparticles, where the most influential parameters are the type of nanoparticles, the concentration of nanoparticles, particle size, hydrophilicity, salinity, temperature, and the presence of surfactant (Ogolo et al., 2012; Moghaddam et al., 2015; Monfared et al., 2016). The increase of wettability alteration from the oil-wet to water-wet was observed in the SDS-SiO_2 system compared to solely SDS system (Ehsan et al., 2017).

Surfactant adsorption on reservoir minerals and rock surfaces can also be very high, which will reduce the available surfactant molecules at the air-water interfaces of the foam, hence, destabilize the foam lamella (Farhadi et al., 2016; Yekeen et al., 2016). Previous studies reported that surfactant adsorption on reservoir rocks increases in the presence of clay mineral (Muherei & Junin, 2007; Daud, 2012; Amirianshoja et al., 2013). Hence, the effectiveness of surfactant foam flooding depends on the extent of surfactant adsorption on reservoir rock surfaces and clay minerals. Other than using a sacrificial agent (Syahputra, 1999; ShamsiJazeyi et al., 2013), the presence of nanoparticles could also reduce surfactant adsorption on clay mineral (Cheraghian, 2017; Yekeen et al., 2017c; Saxena et al., 2018).

1.2 Problem Statement

Though the influence of nanoparticles on stabilizing surfactant foam has been widely investigated, most studies have been carried out in the water-wet system due to the oil-wet system has a detrimental effect on foam generation and stability, especially in the presence of oil. Thus, the role of nanoparticles during stabilizing surfactant foam flooding in oil-wet is yet to be well understood, as foam stabilizer and wettability modifier. The influence of nanoparticles in stabilizing cationic surfactant foam also has not been fully studied in the dynamic test, despite the foam produced by the cationic surfactant was less stable than the anionic type (Bahri et al., 2006; Kumar & Mandal, 2017; Babamahmoudi & Riahi, 2018). However, more effective as wettability modifier compared to the anionic and nonionic type (Jarrahian et al., 2012; Hou et al., 2015; Singh & Mohanty, 2016). Thus, this study is essential to understand the influence of nanoparticles as a foam stabilizer during nanoparticles stabilize cationic surfactant foam, and as a wettability modifier during stabilize anionic surfactant foam.

The CMC of surfactant plays a major role during surfactant-nanoparticles foam flooding, in increasing particle hydrophobicity by in-situ surface activation. Nevertheless, the utilization of the ‘correct CMC’ in salinity brine is not really concerned among previous researchers because most studies were conducted by using deionized water (Vatanparast et al., 2017a; Babamahmoudi & Riahi, 2018; Maurya & Mandal, 2018). Although few studies were conducted by using brine, the surfactant used was limited by using the anionic type (Zargartalebi et al., 2014; Yekeen et al., 2017b). Hence, the effect of cationic surfactant concentration on adsorption index, adsorption energy, and oil displacement test remain inconclusive yet. Due to cationic surfactant is widely used in carbonate reservoir, thus, a depth and comprehensive study on the effect of surfactant concentration during nanoparticles stabilize cationic surfactant foam in salinity brine are required.

When surfactant adsorption on clay increases, the fewer surfactant will be adsorbed on foam interfaces. Although cationic surfactant are more adsorbed on clay minerals compared to anionic surfactant by the electrostatic attraction (Ma et al., 2013; Elias et al., 2016; Rabiu et al., 2016) and the presence of nanoparticles could reduce surfactant adsorption on clay, current studies are still limited by using anionic surfactant (Zargartalebi et al., 2014; Khabashesku et al., 2017; Yekeen et al., 2017b). Hence, a depth study is needed to evaluate the effect of nanoparticles in reducing cationic surfactant adsorption on clay. On the other hand, the utilization of nanoparticles in reducing surfactant adsorption on clay is still limited by using hydrophilic nanoparticles (Zargartalebi et al., 2014; Yekeen et al., 2017c) while the utilization of partially hydrophobic or hydrophobic type is still not studied yet. Thus, it is essential to optimize their utilization, consequently improve foam flooding.

While study wettability alteration during foam flooding by using different anionic surfactant, Singh & Mohanty (2016) showed that solely AOS was unable to alter the wettability of oil-wet despite produced stable foam, whereas APS-68 successfully altered to water-wet although generated unstable foam. As a result, foam flooding of APS-68 and AOS produced 92.3% and 63.8% of oil recovery respectively. Hence, the oil recovery was governed by wettability alteration rather than foam stability. On the other hand, despite that nanoparticles are proven in further altered the oil-wet to water-wet which prior altered by using anionic surfactant (Ehsan et al., 2017), their study only covered wettability alteration without further involve with other EOR, such as foam flooding. Besides, the utilization of cationic surfactant-nanoparticles in wettability alteration is still not studied yet, despite cationic surfactant are more efficient as wettability modifier compared to the anionic surfactant. Thus, a thorough study should be conducted to investigate which factor is dominant during nanoparticles-surfactant foam flooding in the oil-wet porous medium: either by foam stabilization or wettability alteration.

1.3 Research Goal

The goal of this research is to study the effects of nanoparticles during stabilizing surfactant-CO_2 foam flooding in the oil-wet system, where the nanoparticles used are functioned as a foam stabilizer and wettability modifier.

1.3.1 Research Objectives

The specific objectives of this research are:

(a) To investigate the influence of SiO_2 nanoparticles during stabilizing surfactant foam in the static test, and during reducing foam mobility in the oil-wet porous medium in the dynamic test.

(b) To analyze the wettability alteration effect during SiO_2 nanoparticles stabilize surfactant foam flooding in the oil-wet porous medium, including reducing surfactant adsorption on clay.

(c) To study the effect of foam stabilization and wettability alteration during SiO_2 nanoparticles stabilize surfactant-carbon dioxide foam flooding, and which factor is more dominance in oil recovery.

1.4 Scopes of Study

(a) Surfactants used were SDS and CTAB, which represents anionic and cationic surfactant respectively.

(b) The used nanoparticles were hydrophilic SiO_2 and partially hydrophobic SiO_2 (PH SiO_2).

(c) The brine salinity was fixed at 1 wt% (10, 000 ppm) for all experiments by using sodium chloride (NaCl). Besides, this study did not cover the effect of salinity on the aggregation of SiO_2 nanoparticles (due to SiO_2 nanoparticles will aggregate at above 1.5 wt% NaCl).

(d) The CMC of surfactant during the foam test and wettability alteration test was determined by using conductivity meter; while using Du Noüy ring tensiometer during surfactant adsorption on clay test.

(e) The foam static test, wettability alteration test, and surfactant adsorption test were conducted in atmospheric pressure and temperature at 26 ^{o}C.

(f) During foam static test, the foam was generated by using a computer-controlled Krüss Digital Foam Analyzer (DFA). The supplied gas was air due to the CO_2 connector was unavailable. The selected method for half-life foam stability was Ross-Miles ASTM. The flow rate of the air was fixed at 3 ml/min (0.05 cm^3/s). Parameters studied were half-life foam stability, bubble size distribution, bubble shape, and lamella thickness.

(g) The particle contact angle surface wettability was assumed to be similar to the contact angle of glass slide which treated with nanoparticles.

(h) The wettability alteration of carbonate rock was measured by using the contact angle method.

(i) Clay mineral used during surfactant adsorption test was kaolinite, which controlled at 1 wt% for all experiments.

(j) To alter the glass bead from the originally water-wet to oil-wet, the glass bead pack was treated with 4 wt% of dichloromethylsilane in n-hexane.

(k) During the dynamic test, the flow rate of the injected water, paraffin oil, water-flooding, foam flooding, and post-water flooding were all fixed at 0.05 cm^3/s.

(l) The foam flow rate was assumed to be similar to the CO_2 gas flow rate (0.05 cm^3/s) because the system used was pre-generated foam with a fixed volume of surfactant and nanofluid before injected to the glass bead pack.

(m) Treated as single-phase flow, foam apparent viscosity was calculated by using single-phase Darcy law by prior determined the permeability of glass bead pack by flowing brine. The flow was considered as turbulent flow with a high Reynold number.

(n) The foam quality in the static and dynamic test was controlled at 95%.

(o) The optimum concentration of nanoparticles obtained during foam static test was carried in the dynamic test of foam flooding with wettability alteration.

(p) The wettability alteration of the glass bead pack from the oil-wet to water-wet during foam flooding was monitored by foam apparent viscosity and MRF, and the oil-recovery during post-water flooding.

(q) The heterogeneous glass bead pack was prepared according to the permeability difference between layers.

(r) All the dynamic tests of foam flooding were conducted in atmospheric pressure and temperature at 26 ^{o}C.

1.5 Significances of Study

This research has attempted to introduce a new phase of EOR, which is the novelty of this study, double effects of nanoparticles during stabilize surfactant foam flooding: as foam stabilizer and wettability modifier. Since foam flooding is better than WAG in reducing gas mobility (Skauge et al., 2002; Tunio et al., 2012), and foam assisted water alternating gas (FAWAG) is recommended as future EOR in Malaysian oil field (Borhan et al., 2014; Osman et al., 2014), hence, it is anticipated that nanoparticles stabilize surfactant foam or FAWAG flooding could be implemented in Malaysian reservoir. Lastly, by using the oil-wet porous medium, perhaps the result of this study could be utilized in carbonate rock reservoirs, which contributes more than 60% of proven reserves worldwide (Sheng, 2013; Sadeq & Yusoff, 2015).

1.6 Dissertation Outline

This dissertation consists of six chapters. Chapter one explains the background of study, problem statement, objectives of study, scopes of study and significances of study. Chapter two consists of the fundamental concepts of foam, parameters influence foam performance, parameters influence nanoparticles stabilize foam, the fundamental concept of wettability, parameters influence nanoparticles as wettability modifier, the effect of wettability on foam flooding, surfactant adsorption isotherm, and surfactant adsorption on kaolinite. The research methodology is presented in the third chapter. The result and discussion of this research are presented in chapter four. Lastly, the conclusion and recommendation for future studies are listed in chapter five.

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