LIGNIN AS PRE FLUSH REDUCING GEMINI SURFACTANT ADSORPTION ON CLAY MINERALS

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To the loving memory of my beloved mother Sumia Akasha Hilal for all her sacrifices in life.

To my father and my role model Hashim Abbas Baibikir.

and

To my beloved son Amged Bashier for his patience during these years.

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ABSTRACT

In order to increase the oil recovery factor, enhanced oil recovery method has been used to exploit residual oil from the reservoirs. Chemical enhanced oil recovery is one of the proven useful techniques which include injection of surfactant to reduce the oil-water interfacial tension. Recently, the applicability of surfactant to tolerate high salinity and high temperature conditions has resulted in investigation of the new proposed surfactant called aerosol-OT. In this study, the role of clay mineral on aerosol-OT surfactant adsorption, the effect of mineralogical composition and clay mineral percentage on the surfactant adsorption and the effect of salinity and temperature on the adsorption quantity were investigated. Finally, the study examines the effectiveness of alkali lignin as a sacrificial agent for reducing aerosol-OT dynamic adsorption. The experiments were divided into three parts including static adsorption batch experiments, dynamic adsorption in sandpack flood and dynamic adsorption after preflush using alkali lignin. Results of static tests showed that aerosol-OT adsorbed on both sand and clay minerals. Increasing the clay percentage resulted in increase the adsorption, while the increases in temperature reduced the adsorption. The results of adsorption test revealed that the highest adsorption was on kaolinite while the adsorption on illite and montmorillonite surface was significant and should not be ignored. Meanwhile, the adsorption reached its highest value (21 g/kg) in salinity of 60,000 ppm sodium chloride at 25 °C. The dynamic adsorption results showed higher adsorption compared to the static adsorption under the same condition while the increasing trend order remained the same. The maximum adsorption at the dynamic condition was 44 g/kg at the 7% kaolinite sandpack. The alkali lignin was effective to reduce the aerosol-OT adsorption between 25% up to 65% during the dynamic flow. The findings of this study are useful to understand the aerosol-OT adsorption at the reservoir condition and the lignin efficiency as sacrificial agent in reducing aerosol-OT adsorption for further usage in chemical enhanced oil recovery application.

ABSTRAK

Untuk meningkatkan faktor perolehan minyak, kaedah perolehan minyak tertingkat yang lebih baik digunakan untuk mengeksploitasi minyak sisa dari reservoir. Perolehan minyak tertingkat kimia melalui suntikan surfaktan merupakan salah satu teknik yang terbukti berkesan untuk mengurangkan tegangan antara muka air dan minyak. Dalam perkembangan terkini, kebolehgunaan surfaktan untuk bertahan dengan keadaan kemasinan dan suhu yang tinggi telah menjurus kepada kajian terhadap surfaktan baharu yang dipanggil aerosol-OT. Dalam kajian ini, peranan mineral lempung pada penjerapan surfaktan aerosol-OT, kesan ciri-ciri mineralogi dan peratusan mineral lempung pada penjerapan surfaktan, dan kesan kemasinan dan suhu pada kuantiti penjerapan telah dijalankan. Akhirnya, kajian ini mengkaji keberkesanan lignin alkali sebagai korban untuk mengurangkan penjerapan dinamik aerosol-OT. Eksperimen dibahagikan kepada tiga bahagian iaitu eksperimen penjerapan statik kelompok, penjerapan dinamik dalam banjiran pek pasir, dan penjerapan dinamik selepas pra-banjiran menggunakan lignin alkali. Keputusan ujian statik menunjukkan aerosol-OT terjerap pada kedua-dua pasir dan mineral lempung. Peningkatan peratusan lempung dan peningkatan kemasinan menyebabkan peningkatan penjerapan, manakala kenaikan suhu mengurangkan penjerapan. Hasil ujian penjerapan mendedahkan bahawa penjerapan tertinggi berada pada permukaan kaolinit, manakala penjerapan pada permukaan ilit dan montmorilonit adalah signifikan dan tidak boleh diabaikan. Sementara itu, penjerapan mencapai nilai tertinggi (21 g/kg) pada kandungan kemasinan 60,000 ppm natrium Klorida dan 25 °C. Tambahan lagi, hasil penjerapan dinamik menunjukkan penjerapan yang lebih tinggi berbanding dengan penjerapan statik di bawah keadaan yang sama manakala kecenderungan peningkatan tetap sama. Penjerapan maksimum pada keadaan dinamik ialah 44 g/kg pada 7% pasir kaolinit. Lignin alkali berkesan untuk mengurangkan penjerapan aerosol-OT antara 25% hingga 65% semasa aliran dinamik. Penemuan kajian ini berguna untuk memahami sifat penjerapan aerosol-OT pada keadaan reserbor dan kecekapan lignin sebagai agen korban untuk mengurangkan penjerapan aerosol-OT untuk digunakan di dalam aplikasi perolehan minyak tertingkat kimia.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

Γ_{max}	-	Maximum adsorbed amount (g/kg)
A_T	-	Adhesion tension
K_{ro}	-	Oil relative permeability
K_{rw}	-	Water relative permeability
N_C	-	Capillary number
P_A	-	Bulk phase pressure
$\theta\sigma_{so}$	-	Contact angle measured through the water phase.
μ_o	-	Oil viscosity
μ_w	-	Water viscosity
σ_{so}	-	Interfacial tension between the oil and solid
σ_{sw}	-	Interfacial tension between the solid and water
˚C		Degree Celsius (temperature)
$\Delta G^0{}_{H_2O}$	-	The dissolution or solvation of the adsorbate species or any species displaced from the interface due to adsorption.
$\Delta G^0{}_H$	-	Hydrogen bonding energy
$\Delta G^0{}_{chem}$	-	Chemical covalent bonding
$\Delta G^0{}_{c-S}$	-	Free energy due to interactions between the hydrocarbon chains and hydrophobic sites on the solid,
$\Delta G^0{}_{c-c}$	-	Free energy of associate methyl groups in the hydrocarbon chain
$\Delta G^0{}_{elec}$	-	The electrostatic interaction term, , $\Delta G^0{}_{c-c}$ Is the free energy of associate methyl groups in the hydrocarbon chain,
ΔG^0	-	Standard Gibbs energies of micellization
ΔH^0	-	The standard enthalpy of micellization
ΔS^0	-	The standard entropy of micellization

μ	-	Viscosity
A°		Angistrom= ml^{-8} m (distance)
Bbl	-	Barrel (volume)
BET		Brunauer–emmett–teller
C_e	-	Surfactant concentration after equilibrium (g/L).
CEC		Cation exchange capacity
CEOR	-	Chemical enhanced oil recovery.
Cm^2		Square centimeter (volume)
CMC	-	Critical micelle concentration
EDX	-	Energy Dispersive X-ray.
EOR	-	Enhanced oil recovery.
g		Gram (mass)
g/L		Gram per litre (concentration)
IFT	-	Interificial tension.
in		Inch (diameter)
K		Kelvin (temperature)
K_F	-	Equilibrium Freundlich constant
Kg		Kilogram (mass)
K_L	-	Langmuir constant (L/g)
L		Litre (volume)
mM		Millimolar10^{-3} mol/L (concentration)
mN/m		Milli-Newton/m =dyne/cm(ST/IFT)
n	-	Freundlich constant
N		Newton (force)
NaCl	-	Sodium chloride salt
pH	-	potential of hydrogen ($-\log_{10} c$)
Ppm		Part per million
PV	-	Pore volume.
q	-	Flow rate (ml/s)
R	-	Gas constant (J mol^{-1} K^{-1})
R^2	-	Correlation coefficient
SEM	-	Scanning electron microscope
u	-	Displacing fluid velocity

UTM	-	Universiti teknologi malaysia
UV	-	Ultra violet
Wt%		Weight percentage
X_{CMC}	-	Micellization mole fraction concentration
XRD	-	X-ray diffraction
β	-	Counter ion bound for micellization
ΔP	-	Differential pressure (atm)
Γ	-	Surfactant adsorption density (g/Kg)
M	-	Mobility
T	-	Temperature
Zpc	-	Zero potential point
λ	-	Wavelength of the X-rays,

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Overview

Oil is the most used non-renewable source of energy in the world. Operation and service companies invest on many potential applications to increase oil production. The continuous research provides several solutions for existing techniques and new solution. Some of these techniques includes new well completion, digital well monitoring, multi-layer horizontal wells and optimizing sweep efficiency by enhanced oil recovery (EOR) (Raniolo *et al.*, 2014). EOR is a target for several researches. The ability of EOR to increase oil production from depleted reservoirs cannot be ignored (Bhattacharya *et al.*, 2016; Goodyear, 2016).

EOR method has been investigated on several levels in order to select the best application. The screening criteria of each method depend on the reservoir history (Moreno *et al.*, 2014). Several EOR methods have been introduced including thermal EOR and non-thermal methods. Chemical enhanced oil recovery (CEOR) is a non-thermal method; it has shown high applicability in several conditions. Thus, it has been under the spotlight for decades. Chemical flooding works by injecting chemicals not existing in reservoir to improve the sweep efficiency. Several chemicals have been introduced such as polymer, surfactant, alkalines and recently nanoparticles (Kim *et al.*, 2017; Sabzabadi *et al.*, 2014; Thomas, 2006).

In EOR flooding, surfactant lowers the interfacial tension (IFT) between the water and oil phases, besides altering the rock wettability and improving mobility

(Kamal *et al.*, 2017). The unique ability of surfactant to reduce the IFT is because of the molecule composition. The head of surfactants is a polar while the tail is non polar. The head lies within the aqueous phase of the interface while the hydrophobic tail extends into the oil phase.

The main reason for using surfactant is to reduce the oil–water IFT to low values. Lately new studies are focused on increasing the ability of surfactant to lower the IFT to 10^{-5} or 10^{-4} (Sheng, 2015b).The revolutionary development in surfactant manufacturing has made low IFT possible (Babu *et al.*, 2016; Gao and Sharma, 2012; Li *et al.*, 2016b). Technicaly, surfactants may be present in a hydrocarbon solvent or in an aqueous solution or in a combination of both. It can vary in concentration between 0.01 to 10.0% wt. The total number of pore volume injected varies between 15-60% PV for low concentration solutions or between 3-10% PV for high concentration solutions (Alvarado and Manrique, 2010).

The surfactant cost has severe effect on the economics of CEOR. For example, the cost for CEOR within the 1970s and 1980s were low based on oil price at that time. However, surfactant formulation cost was between USD 0.90 -2.75 /bbl injected, whereas, a micellar formulation would cost (20 -75) USD/bbl injected (Chan *et al.*, 2014; Watkins, 2009). For surfactant to work effectively at the oil water interface, it needs sufficient concentration. Whereas, the main problem with surfactant is the concentration loss (He *et al.*, 2015).

Several reasons were proposed for surfactant losses such as rock matrix, precipitation and phase behaviour changes. For each surfactant, the loss is expected and it need to be evaluated especially, if it result from a non-avoided condition such as reservoir rocks (Li *et al.*, 2016a).

1.2 Background of Study

Adsorption is defined as the adhesion of gas, liquid, or dissolved solids molecules to a surface (Dąbrowski, 2001). This process creates a film on the surface of the adsorbent (surface of accumulation). Molecules may collect by the external surface or internal surface such as walls of capillaries of the solids or by the surface of liquids. There are two types of adsorption; physical adsorption and chemisorption. Chemisorption is the electrostatic chemical bonding between adsorbate and the adsorbent (Dąbrowski, 2001; Uddin, 2017).

The adsorption of surfactant in porous media is a complex phenomena where surfactant molecules transfer from the bulk solution to the rock-fluid interface (Bera *et al.*, 2013). This phenomenon happens if the interface is energetically favored by the surfactant in comparison to the bulk solution The process includes mass transfer and chemical reactions (Zhang and Somasundaran, 2006). The surfactant nature, reservoir rock properties (mineralogy and sand-shale cut off) and environment factors (salinity, pH, concentration and temperature) were found to highly influence the surfactant adsorption (Elias *et al.*, 2016; Gogoi, 2011; Howe *et al.*, 2014).

As most of surfactant flooding operations were applied in sandstone reservoir, it is very important to understand the surfactant adsorption on it. Sandstone reservoirs are sedimentary rocks composed of coarse grains bonded by natural cement and solidified when buried (Von Engelhardt and Zimmermann, 1988). Sandstone reservoirs usually consist of quartz, feldspar, rock fragment, it also contain fine grained clay minerals that have chemical composition and crystal structure characteristics (Eslinger and Pevear, 1988).

Clay mineral is composed of hydrous aluminium silicates. The clay minerals are horizontally layered with two basic layers (octahedral and tetrahedral) repeated in sequence. The octahedral layer is made up of oxygen, hydroxyls and aluminium ions respectively, with the aluminium ion in the centre. Tetrahedral layers are composed of oxygen and silicon in the centre. Both layers (tetrahedral and octahedral) combine by sharing oxygen or hydroxyls. This arrangement is responsible for the differences in the clay group's chemical properties as well as the significance of each clay compound in the same group (Bergaya and Lagaly, 2006).

Clay mineral chemical properties are usually influenced by the type and amount of exchangeable ions, also referred to as surface charge. For example, the clay mineral layer of the kaolinite group (1:1) differs from that of the illite group (2:1). Surface charge can be produced by adsorption of an ion (the solid acts as an electrode). In clay-aqueous system, the potential of exchanging ions between the liquid and solid depends on the concept of zero potential point (Zpc). If the pH is more than the Zpc point, the clay will act as a base and if lower, will act as an acid. The generated chemical reaction follows the chemical ion exchange or substitution according to the ion strength. This reaction triggers the adsorption on different levels until it neutralizes the clay (Eslinger and Pevear, 1988).

The role of clay mineral on the surfactant adsorption was investigated at several levels such as: the type of mineral (kaolinite, illite and montmorillonite), mechanism (ShamsiJazeyi *et al.*, 2014a; Somasundaran *et al.*, 1983), adsorption capacity (Atay *et al.*, 2002; Elias *et al.*, 2016), clay fraction (Amirianshoja *et al.*, 2013), surfactant nature (Sánchez-Martín *et al.*, 2008), existing cations (Yekeen *et al.*, 2017), effect of pH (Djebbar *et al.*, 2012) and mixed surfactant on the reservoir rock (Muherei and Junin, 2009). Whereas, the effect of salinity and temperature is yet to be investigated to a reasonable extent.

It is evident from documented research that a lot of progress has been made regarding the fundamental principles on the surfactant adsorption. But, the role of mineralogy on anionic surfactant was not fully examined, since the ultimate focus was given to cationic surfactant and non-ionic surfactant. Furthermore, extensive experimental studies has proven that surfactant adsorption characteristic and capacity is not similar for each test (Kamal *et al.*, 2017; Saha *et al.*, 2017). Therefore, the need to examine surfactant individually is required to determine their suitability in CEOR application (Ahmadi and Shadizadeh, 2015b).

In recent years, the need to apply surfactants at reservoir temperature and salinity led to the recommendation of a group of surfactants known as Gemini Surfactants. This name was given to a group of amphiphiles with a hydrocarbon tail, an ionic group, a spacer, a second ionic group, and another hydrocarbon tail. This class of surfactants consist of a rich variety of anionic and cationic surfactants (Zana and Talmon, 1993). Anionic Geminis in particular, have high water solubility, it can form micelles, decreases the surface tension, and shows good rheological behaviour compared to conventional anionic surfactants (Shukla and Tyagi, 2006).

The characteristics of Gemini surfactants over conventional ones that make them to be sought after are their increased surface activity, lower critical micelle concentration (CMC), and useful viscoelastic properties such as effective thickening. Gemini surfactant has shown good results in high salinity. Gemini surfactants only need 0.02 wt% to achieve CMC and it can handle salinity up to 200,000 mg/L compared to conventional surfactants (Gao and Sharma, 2012; Kumar and Tyagi, 2014, 2015). These unique properties of Gemini surfactant, means that they have great potential for application in the CEOR.

Aerosol-OT is anionic Gemini surfactant available in commercial quantity as sodium bis (2-ethylhexyl) sulfosuccinate. It is a sulfonated hydrocarbon and has found usefullness in chemical and biophysical works. Aerosol-OT has been endorsed for CEOR and monitored for high salinity and phase behaviour (ElMofty, 2012). Moreover, the microemulsion of Aerosol-OT in oil/water system was found to be very promising (Moulik and Mukherjee, 1996; Wesson *et al.*, 2012). The adsorption of Aereosol-OT is higher than the conventional surfactant on natural soil (Atay *et al.*, 2002). Also, the study on kaolinite showed high adsorption (Behrens, 2013). In order to overcome the lack of understanding in Aerosol-OT adsorption on minerals it needs to be studied more on different mineralogical characteristic.

Despite the risk factor brought by adsorption phenomena, researchers have proposed several solutions to minimize the adsorption such as; optimizing the surfactants and use of co-chemical could help in surfactant adsorption reduction. Surfactant optimization was proposed by matching the surfactant to work on specific rock types. However, this solution could increase the cost; it may not be fully applicable in all reservoir zones. The second option is the use of different chemical to adsorb, instead of the surfactant found. The chemicals that are generally used with or before injecting surfactants with the aim of preventing the surfactants from exhibiting the adsorption sites are called sacrificial agents (Southwick *et al.*, 2014).

The performance of sacrificial agents, depend on the rock type and clay mineral nature. Moreover, the adsorption reduction varies according to the anionic surfactant used. The selection of sacrificial agent is also affected by its availability, cost and its ability to minimize surfactant adsorption to the minimum. Several sacrificial agents were proposed such as, alkali, cellulose, polybasic carboxylic acids, sodium polyacrylate and ionic liquid (Hanamertani *et al.*, 2017; Kalfoglou, 1977; ShamsiJazeyi *et al.*, 2014b).

Alkali lignin has been found to be very successful in minimizing the adsorption on different clay minerals with wide range of anionic surfactants. Additionally, it can help to lower the IFT (Chen *et al.*, 2016; Feng *et al.*, 2012; Johnson Jr and Westmoreland, 1982). Furthermore, alkali lignin is cost-effective since it could be found as waste material from several industries such as paper pulp.

1.3 Problem Statement

It has been proven that surfactant has the ability to reduce IFT between oil and water and to alter rock wettabiltity. Therfore, it can increase the sweep efficiency and increase oil recovery. Furthermore, experiments and field application have been conducted for increasing oil recovery in sandstone reservoirs. However, the ability of anionic surfactant to withstand high salinity and high temperature condition was not fully achieved (Negin *et al*., 2017; Sheng, 2015). The need to find anionic surfactant to be applied at high salinity and high temperature condition motivated researchers to find suitable surfactant. Therfore, the anionic Gemini surfactant and Aerosol-OT were recommended (ElMofty, 2012; Gao and Sharma, 2012).

Despite the recommendation made for Aerosol-OT surfactant, it is still in experimental stage and not yet fully examined. The ability of any type of surfactant in achieving recovery is affected by the risk factor of adsorption on rock and mineral surfaces. Adsorption has been the subject of many researchers. Aerosol-OT surfactant showed evidence on high adsorption and concentration reduction in the presence of soil, sandstone and kaolinite (Atay *et al*., 2002; Behrens, 2013; Wesson et al., 2012). However, the previous studies were limited to describing the role of different mineralogical composition or the effect of clay fraction. Furthermore, previous studies did not include surfactant adsorption at high salinity and high temperature conditions.

Therefore, there is a need to find the solution to minimize the adsorption. In recent years the ability of alkali lignin to reduce different surfactant adsorption was investigated and also recommended (Chen *et al*., 2016; Feng *et al*., 2012). Thus, the alkali lignin was be used as preflush sacrificial agent to lower Aerosol-OT adsorption. The effectiveness of alkali lignin was determined on several clay minerals.

Thus, this study will solve the following problems:

1. How does different mineralogical types (quartz, kaolinite, illite and montmorillonite) influence (Aerosol-OT) adsorption at different salinities and temperatures?
2. How does the clay content affect the dynamic adsorption of Aerosol-OT surfactant in flooding?
3. How effective is lignin as a sacrificial agent in reducing surfactant loss on the different clay minerals?

1.4 Research Objectives

This research focused on determining the adsorption of Aerosol-OT on clay minerals at different salinity and temperature. The experiment was conducted for both static and dynamic conditions. Furthermore, it is focused on minimizing the dynamic adsorption by using alkali lignin as a sacrificial agent. The reduction of Aerosol-OT adsorption by alkali-lignin preflush was investigated using different sandpack containing different clay mineral percentages.

1. To quantify the static adsorption of Aerosol-OT surfactant on quartz-sand, kaolinite, illite and montmorillonite at different salinity and temperature.
2. To determine the dynamic adsorption of Aerosol-OT on different quartz-sand/clay mineral concentrations.
3. To examine the effectiveness of alkali lignin as a sacrificial agent by determining the reduction of Aerosol-OT dynamic adsorption.

1.5 Scope of Study

This research will focus on the influence of different critical parameters on the static and dynamic adsorption of Aerosol-OT surfactant on sand-quartz, kaolinite, illite and montmorillonite minerals.

1. The influence of four NaCl concentrations (0 ppm, 3500 ppm, 20000 ppm, 35000 ppm, 60000 ppm) on micellization behaviour was determined using the surface tension method.
2. The effect of temperature (25, 45, 65, 85, 105 °C) on CMC was determined and the corresponding thermodynamic parameters ($\Delta S, \Delta H\ \Delta G$) were extracted.
3. Quartz-sand, kaolinite, illite and montmorillonite were characterized using XRD, SEM, EDX, BET, CEC, Zpc.
4. The surfactant adsorption (g/Kg) on sand and clay minerals content (in the range of 0, 2%, 5% and 10%) was determined using surface tension method and UV-vis spectroscopy.

5. For the adsorption experiments, the influence of high salinity conditions (20000 ppm, 35000 ppm and 60000 ppm) and two temperature conditions (45°C and 85°C) in the presence of each adsorbent were determined.
6. The theoretical analysis for adsorption isotherms was conducted using Freundlich and Langmuir adsorption isotherm.
7. The performance of lignin pre-flush to reduce surfactant adsorptions was observed. Also, the surfactant concentration measured after using various pre-flush with different pH on different range of clay mineral fraction in sand pack.
8. The static and dynamic adsorption experiments were done in the absence of oil so that partioning of surfactant will be avoided.

1.6 Significance of the Study

The novelty of this research can be listed as follows:

1. This study provides insight into enhanced oil recovery and potential use of Aerosol-OT in term of micellization behaviour at reservoir temperature and salinity.
2. The systematic experiments conducted to understand the Aerosol-OT adsorption on reservoir rock minerals (quartz, kaolinite, illite and montmorollonite) within the effect of reservoir temperature and salinity
3. The results quantified the surfactant adsorption and losses in dynamic and static conditions.
4. It also provided insight into the use of sacrificial agent preflush to minimize Aerosol-OT adsorption.

The significance of the study can be listed as follows:

1. The research is applicable to the field practice as the effect of salinity range and reservoir temperature was considered.

2. Due to the risk of loosing surfactant concentration on the project budget, minimizing surfactan adsorption in the oil industry is needed. The research reflected the ability of reducing surfactant adsorption by using less cost material as Alkali lignin preflush.

3. The findings of this study have versatile applications for researchers and scientists in other fields such as environment in the cleaning of contaminated site, and in drilling engineering for the decontamination of drilling cuttings.

1.7 Thesis Outline

The current thesis has been divided into seven chapters and three appendices. The definition of adsorption term and the clarification of the role of clay minerals are presented in the current chapter. The problem of the research along with the proposed objectives and its contribution are reported, followed by the study outlines. In chapter two, introductory information about chemical CEOR application, on going projects and selection criteria are provided. It also explains the role of minerals in sandstone reservoirs. Surfactant and micellization behaviour under different parameters were investigated. This section also explains the mechanism of anionic surfactant adsorption. The possibility of reducing adsorption and previous research were reviewed.

In Chapter three, the laboratory methods performed to charectrize the minerals were explained for each equipment used. The methods of surface tension and relevant CMC determination are described. The steps used to measure the static adsorption test are provided. Also, the sandpack preparation and charactrization methods were provided in details. The dynamic flow adsorption and Uv-vis spectroscopy measurement is provided. Sacrificial agent preflush experimental steps are explained.

Chapter four explained the micellization behaviour and corresponding CMC resuts as well as the thermodynamic parameters were calculated.

In Chapter five, the main focus is to provide detailed explanation and results for the first objective. The results of Aerosol-OT adsorption on minerals were presented in tables and figures. The results explained for all studied parameters are provided individualy in sections.

In Chapter six, the experimental results are divided to two main parts related to each other. The first part determines the dynamic adsorption on different clay mineral percentages. The sand packs properties results were included. The second part covers the third objective. The sacrificial agent flooding screening results was explained. The surfactant adsorption results after preflush was explained.

Chapter seven is a summary of the conclusions reached through this research.

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