EFFECTS OF SALINITY ON NANOSILICA APPLICATIONS IN ALTERING LIMESTONE ROCK WETTABILITY FOR ENHANCED OIL RECOVERY

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To my beloved The Almighty, Allah S.W.T.,

To my beloved Prophet Muhammad S.A.W.,

To my beloved mother and father

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ABSTRACT

The role of nanoparticles in enhancing oil recovery from oil reservoirs is an increasingly important topic of research. Nanoparticles have the properties that are potentially useful for enhanced oil recovery processes, as they are solid and two orders of magnitude smaller than colloidal particles. One of the important roles of nanoparticles in petroleum industry is to change the wettability of reservoir rocks. However, there are many parameters that can affect nanoparticles applications in porous media. Parameters such as various concentrations of nanoparticles, presence of different salinities, amount of clays, type of crude oil and temperature. The main objective of this project was to investigate the efficiency of silica nanoparticles in enhancing oil recovery in the presence of formation brine with different concentrations. The methodology of this study involved several laboratory tests. It is divided into two main sections with the aim of enhance oil recovery of oil wet reservoirs. First, the wettability alteration and oil–water interfacial tension modification induced by introducing different concentrations of nanosilica (0.01, 0.05, 0.1wt%) and different concentrations of NaCl formation brine (0.3, 1, 2, 3, 4 wt%) was studied by experimental approach. Second, the displacement test for determining oil recovery for those different concentrations of nanosilica and formation brine. There exists an optimal nanoslica concentration for varying salinity and an optimal salinity for varying nanosilica concentration at which the wettability alteration on oil wet limestone is the maximum for the study. The results revealed that IFT and contact angle tests were found to have the same optimal salinity (0.3 wt%) and optimal nanosilica concentration (0.1 wt%) where by these concentrations the IFT reduced in reservoir to 12 mN/m and the lowest contact angle (53^{o}) was obtained. Furthermore, the highest value of displacement efficiency obtained at nanosilica 0.05wt% and salinity 0.3 wt% NaCl where the reduction of residual oil saturation was less than 6 points %. As conclusion, as the salinity increases, the extent of wettability alteration, IFT reduction, and enhanced oil recovery by nanosilica decreases.

ABSTRAK

Peranan nanopartikel dalam meningkatkan perolehan minyak dari reservoir minyak adalah satu topik yang semakin penting dalam penyelidikan. Nanopartikel mempunyai ciri-ciri yang berguna untuk proses perolehan minyak tertingkat, kerana ia adalah pepejal dan bersaiz lebih kecil daripada zarah koloid. Salah satu peranan penting nanopartikel dalam industri petroleum adalah untuk mengubah kebolehbasahan batuan reservoir. Walau bagaimanapun, terdapat banyak parameter yang boleh menjejaskan aplikasi nanopartikel dalam media berliang. Parameter seperti pelbagai kepekatan nanopartikel, kehadiran kemasinan yang berbeza, jumlah lempung, jenis minyak mentah dan suhu. Objektif utama projek ini adalah untuk menyiasat kecekapan nanopartikel silika dalam perolehan minyak tertingkat dengan kehadiran air garam formasi dengan kepekatan yang berbeza. Metodologi kajian ini melibatkan beberapa ujian makmal. Ia dibahagikan kepada dua bahagian utama dengan tujuan untuk meningkatkan perolehan minyak bagi reservoir basah minyak. Pertama, pengubahan kebolehbasahan dan pengubahsuaian ketegangan antara muka minyak-air disebabkan dengan memperkenalkan kepekatan nano silika (0.01, 0.05, 0.1wt%) dan kepekatan NaCl yang berbeza air garam formasi (0.3, 1, 2, 3, 4% berat) telah dikaji oleh pendekatan eksperimen. Kedua, ujian anjakan untuk menentukan perolehan minyak yang berbeza kepekatan nanosilika dan air garam formasi. Kewujudan kepekatan nanoslika optimum untuk pelbagai kemasinan dan kemasinan optimum untuk pelbagai kepekatan nanosilika di mana pengubahan kebolehbasahan pada batu kapur basah minyak yang maksimum bagi kajian ini. Keputusan mendedahkan bahawa ujian IFT dan sudut sentuh didapati mempunyai kemasinan yang sama yang optimum (0.3% berat) dan kepekatan nanosilica optimum (0.1% berat) di mana dengan kepekatan ini, IFT batuan reservoir berkurang kepada 12 mN / m dan sudut sentuh yang paling rendah (53^o) telah diperolehi. Disamping itu, nilai kecekapan anjakan tertinggi nanosilika 0.05wt% dan kemasinan 0.3% berat NaCl, didapati pengurangan ketepuan minyak baki adalah berkurang kepada 6 mata%. Kesimpulannya, apabila kemasinan yang meningkat didapati tahap pengubahan kebolehbasahan, pengurangan IFT, dan perolehan minyak dengan menggunakan nanosilika didapati berkurang.

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LIST OF ABBREVIATIONS

ASP	–	Alkali-Surfactant-Polymer
AP	–	Alkali-Polymer
API	–	American Petroleum Institute
BPD	–	Barrel Per Day
EOR	–	Enhanced Oil Recovery
HPAI	–	High Pressure Air Injection
IFT	–	Interfacial Tension
IOR	–	Improved Oil Recovery
MEOR	–	Microbial Enhanced Oil Recovery
PAM	–	Polyacrylamide
PV	–	Pore Volume
SP	–	Surfactant-Polymer
TDS	–	Total Dissolved Solids
NP	–	Nanoparticle
LHNP	–	Lipophobic Hydrophilic Nanoparticle
HLNP	–	Hydrophobic Lipophilic Nanoparticle
WF	–	Water Flooding

LIST OF SYMBOLS

D, dim.	-	Diameter
l	-	Length
Δ	-	Difference
W	-	Weight
P	-	Pressure
Q, q	-	Volumetric flow-rate
T	-	Temperature
h	-	Thickness
V	-	Volume
ϕ	-	Porosity
ρ	-	Density
μ	-	Viscosity
PV	-	Pore Volume
K	-	Permeability
R_L	-	Length-to-Thickness Ratio
Θ	-	Angle (^{o})

CHAPTER 1

INTRODUCTION

1.1 Background

Energy resources demand is always up and increasing since the wheel of economy is creating new opportunities to cover up the increasing population of the earth. Depletion of oil reservoir is one of the major problems faced by the petroleum industry and great part of this industry technology is focused on retrieving oil portions left in formation's strata after the reservoir has exhausted its natural energy. Every reservoir, whether mature, recently discovered or even yet to be discovered, are all potential candidates for enhanced oil recovery (EOR). During the past five decades or so, an array of improved/enhanced oil recovery methods have been developed and applied to mature and mostly depleted oil reservoirs. These methods help improve the efficiency of oil recovery by extracting a good part of oil left behind in the reservoir after primary and secondary recovery processes.

Primary recovery process involves displacing oil from porous rocks in the reservoir towards the production well using its own reservoir energy such as natural water drive, gas-cap drive or gravity drainage. Primary methods extract only about 30% to 40% of the original oil in place (Nielson, 1989).

In secondary recovery, a fluid (most commonly water) is injected into the reservoir in order to maintain reservoir pressure and continue oil displacement into the wellbore. Brine salinity has been studied in the literature that it has a profound effect on the interfacial tension, reservoir wettability and oil recovery. Saline water is classified into three categories by US Geological Survey according to the salinity concentration level. The slightly saline water has around 1000 to 3000 ppm of salt. Moderately saline water is roughly about 3000 to 10,000 ppm, and highly saline water is in the range of 10,000 to 35,000 ppm. Seawater has a salinity of roughly 35,000 ppm, and it varies with location. Based on the fact that an optimal salinity of the dissolved solids in the injection water may yield the highest oil recovery, the application of suitable brine salinity is important to improve oil recovery in existing and future water flooding projects.

Chemical EOR had been most active in 1980s and although thermal and gas-miscible EOR had the leading place for EOR methods; chemical EOR is still used until today effectively in many reservoir cases (Gogarty, 1983). Different chemical methods which use, has different effects on the reservoir or crude oil which involves the application of external forces, and substances to manipulate chemical and physical interactions in hydrocarbon reservoirs in a manner that promotes favorable recovery conditions.

Nanotechnology has been developed in various fields in the past few decades. In the petroleum industry, applications of nanoparticles contribute to the exploration, formation evaluation, well drilling, production, enhanced oil recovery, etc. (Shen et al., 2006). Potential applications of nanotechnologies in oil industry include: injection of nanoparticles (nano sensors) into tight oil-bearing sandstones for data collection/characterisation of reservoirs; drilling fluid mixed with nanoparticles for wettability alteration and drag reduction; effect of nanoparticle size exclusion on the efficiency of EOR. This new technology developed in Nano-science has provided an alternative for the generation of stable CO_2 foam. Generally injection of nanoparticles in an oil reservoir may modify the rheology, mobility, wettability and other properties of fluids and moreover need comprehensive investigation. For example certain types of nanoparticles can be used as tracers for oil exploration and other may be used in oil fields. Aluminium oxide (Al_2O_3) reduces oil viscosity while silicon oxide (SiO_2) changes rock wettability in addition to reduction of interfacial tension between oil and water caused by the presence of ethanol.

Taber et al. (1997) shows that 60 % of carbonate rocks were intermediate-wet, 28% were oil-wet and 8% were water-wet. Consequently controlling wettability is become a great challenge in oil and gas industry. Altering the rock wettability considers one of the most challenging problems. The ability of nanoparticles to alter the certain factors in the formation and in oil properties can be taken advantages of, to enhance oil recovery. This involves introducing these nanoparticles to the reservoir and studying its effects on oil properties. It has been reported that water wet formations produce better than oil formations. The wettability of a formation can be changed by using nanoparticles. So nanoparticles are able to change the wettability of rock which means they are able to lead us to enhance oil recovery.

Nanoparticles can improve fluid-rock interaction characteristics such as wettability alternation and heat transfer coefficient enhancement. Also, reduction of IFT and improving displacement efficiency is counted as its advantages (Ju et al., 2006). There are many parameters that can affect nanoparticles applications in porous media. These parameters are including nanoparticles characteristics, porous media features, fluid properties, and operational conditions. As it mentioned, the effects of parameters on application of these nanoparticles have been evaluated in porous media. Parameters such as various concentrations of nanoparticles, presence of different salinities, amount of clays, type of crude oil and temperature.

In this study, wettability alteration induced by introducing different concentrations of NaCl brine and different concentrations of nanosilica was studied by experimental approach. Effects of nanosilica on IFT in presence of different brine concentration are also studied. The influences of concentrations of both brine and nanosilica on oil recovery were analyzed by experimental tests.

1.2 Problem Statement

SiO_2 Nano-Powder is a new type of augmented injection agent that has the ability of stronger hydrophobicity and lipophilicity, and can be adsorbed on the rock surface so that it changes the rock wettability. On the other hand, it can reduce the flow resistance between two phases (IFT), enhance oil effective permeability and reduce injection pressure and augment injection rate. Concentrations of brine salinity can have an effect on application of nanosilica to alter limestone rock wettability. There are many parameters that can affect nanoparticles applications in porous media. One of the most important parameter is the concentration of brine salinity.

As far as it goes, many studies addressed the issues of the application of nanosilica in oilfields to enhance water injection by virtue of changing the wettability of reservoir rock through their adsorption on porous walls of formations but unfortunately, no one of them mentioned the effects of different concentrations of brine on nanosilica applications.

The aim of this study is to investigate optimal nanosilica concentration for varying salinity and an optimal salinity for varying nanosilica concentration at which the wettability alteration on oil wet limestone rock obtained.

The mechanism of wettability alteration by nanosilica on carbonates has not been understood completely. There is lack of study on nanoparticles effect in presence of crude oil in porous media. Moreover no literature has shown the effects of brine concentration on nanosilica.

1.3 Objectives

The objectives of this study are:

a) To determine the effectiveness of different formation brine concentrations on nanosilica applications in altering limestone rock wettability and reducing interfacial tension between fluids.

b) To evaluate the performance of oil recovery by introduce nanosilica at different brine concentrations.

1.4 Scope of Work

The scopes of this study are including:

1. Preparation of SiO_2 nanoparticle suspension in different concentrations (0.01, 0.05, 0.1%wt) in de-ionized water.

2. Preparation of brine by making use of NaCl with different concentrations (0.3, 1, 2, 3, 4% wt).

3. Preparation of sandpack by crushing limestone and utilizing crushed limestone as porous media.

4. Sandpack characterization including determination of pore volume, porosity and permeability.

All tests are run at ambient condition.

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