APPLICATION OF POLYMERIC NANOFLUIDS FOR ENHANCED OIL RECOVERY IN MID-PERMEABILITY SANDSTONE

GBADAMOSI AFEEZ OLAYINKA

A thesis submitted in fulfilment of the
requirements for the award of the degree of
Doctor of Philosophy

School of Chemical and Energy Engineering
Faculty of Engineering
Universiti Teknologi Malaysia

OCTOBER 2019

DEDICATION

This thesis is dedicated to Almighty Allah (SWT) for His countless blessings.

ACKNOWLEDGEMENT

All praises are due to Allah whose grace alone brings all good things to fruition. May the peace and blessings of Allah be upon prophet Muhammad (SAW), his family, companions and those who follow his guidance until the Day of Resurrection (Amin).

My profound gratitude goes to my supervisors, Prof. Dr. Radzuan bin Junin and Prof. Madya Dr. Muhammad A. bin Manan, for their guidance and support during this research. There resourcefulness and assistance have proved vital for the successful completion of this program.

My earnest gratitude and appreciation go to my parent; Dr and Mrs B. Gbadamosi for believing in my dreams, and for always been there for me in every way possible. Besides, I will like to appreciate my virtuous wife, Zainab Abdulkareem-Gbadamosi for her unflinching support, patience and understanding during the study. Additionally, I will like to thank my brothers; Saheed Olalekan and Mubarak Adedamola, and sister Barakat Abimbola for their encouragement, support and kind words.

Finally, many thanks to Universiti Teknologi Malaysia for providing the platform and conducive environment. Gratitude to my friends; Mustapha Babajide Ismail, Augustine Agi, Jeffrey Oseh, Abdulkareem Muyideen, Olohunde Taoheed, and Abdulrasheed Abdulrahman for their innumerable support. I also appreciate the efforts of the laboratory technicians, academic and non-academic staffs, and colleagues at School of Chemical and Energy Engineering for their numerous supports.

ABSTRACT

Enhanced Oil Recovery (EOR) processes are used to recover bypassed and residual oil trapped in a reservoir after primary and secondary recovery methods. Recently, polymeric nanofluid, a novel material formed from the incorporation of polymer and nanoparticle has gained prodigious attention and is proposed for EOR due to its sterling and fascinating properties. Nonetheless, previous studies have focussed more on the suitability of inorganic silica and non-metallic polymeric nanofluids (PNFs). Besides, the performance evaluation of PNFs on pore scale displacement efficiency remains obscure while the mechanistic understanding of this novel material for heavy oil recovery in typical reservoir conditions is elusive in literature. The aim of this study is to explore and exploit the effect of nanoparticles on rheological properties of partially hydrolysed polyacrylamide (HPAM) at varying electrolyte concentration and temperature conditions. Besides, IFT and wettability alteration potential of the PNFs in the presence of heavy oil were evaluated. Herein, two PNFs namely silicon dioxide (SiO_2) and aluminium oxide (Al_2O_3), formulated from the combination of the individual nanoparticles and HPAM were exclusively studied. The nanoparticles were characterised using transmission electron microscopy, while the formulated PNFs were characterised using Fourier transform infrared microscopy and thermo gravimetric analysis to determine the morphology and thermal stability respectively. The rheological properties of the PNFs and HPAM were determined using Brookfield RST. Furthermore, the behaviour of the PNFs and HPAM at oil-water interface was investigated using Kruss tensiometer. Moreover, the wettability effect of the fluids in sandstone cores was examined using DataPhysics optical contact angle equipment. Finally, heavy oil displacement in mid-permeability sandstone cores at typical reservoir condition was carried out using HPHT core flooding equipment. Experimental results show that the rheological properties improved while degradation of HPAM molecules was inhibited due to the addition of NPs. At 2,000 ppm HPAM solution (27 mol % hydrolysis degree), 0.1 wt.% NP concentration was found to be the optimal choice for Al_2O_3 and SiO_2 NP which gives rise to the highest viscosity on the rheological characterization. PNFs exhibited better steady shear viscosity performance under the different electrolyte concentration and temperature studied due to shielding effects. Besides, PNFs lowers IFT of heavy oil due to irreversible adsorption of the NP's at the oil-water interface. Moreover, PNF's alter wettability of sandstone cores from oil-wet to water-wet due to structural disjoining pressure mechanism. Field emission scanning electron microscope and energy-dispersive x-ray analysis confirm adsorption of nanoparticles on the sandstone cores. Finally, heavy oil displacement test in mid-permeability sandstone cores showed that incremental oil recoveries of Al_2O_3 and SiO_2 PNFs at their optimum concentration were 10.6% and 6.1% respectively over HPAM. Physical filtration phenomena lowered the efficiency of the PNF's at higher concentrations. The synergic combination of NPs and polymer resulted in enhanced properties of HPAM, hence, culminating in enhanced sweep and pore scale displacement efficiencies. This study is beneficial for extending the frontiers of knowledge in nanotechnology application for EOR.

ABSTRAK

Proses perolehan minyak tertingkat (EOR) digunakan untuk memperoleh minyak terpintas dan baki minyak terperangkap di dalam reservoir selepas kaedah perolehan primer dan sekunder. Ketika ini, nanobendalir polimer, iaitu bahan novel yang terbentuk daripada gabungan polimer dan nanopartikel telah menarik banyak perhatian dan dicadangkan penggunaannya dalam EOR berikutan sifatnya yang menarik. Walau bagaimanapun, kajian terdahulu lebih tertumpu terhadap kesesuaian nanobendalir polimer silika tak organik dan nanobendalir polimer bukan logam (PNF). Selain itu, penilaian terhadap prestasi PNF pada kecekapan anjakan skala liang masih kabur, dengan kefahaman tentang mekanisma bahan novel ini untuk memperoleh minyak berat pada keadaan tipikal reservoir masih terhad dalam literatur. Tujuan kajian ini adalah untuk meneroka dan mengeksploitasi kesan nanopartikel terhadap sifat reologi poliakrilamida separa hidrolisis (HPAM) pada kepekatan elektrolit yang berbeza dan keadaan suhu yang berlainan. Di samping itu, nilai IFT dan potensi perubahan keterbasahan PNF dengan kehadiran minyak berat turut dikaji. Dua jenis PNF, iaitu silika dioksida (SiO_2) dan aluminium oksida (Al_2O_3), yang dirumus daripada gabungan nanopartikel individu dan HPAM telah dikaji secara terperinci. Pencirian nanopartikel dilaksana menerusi penggunaan alat mikroskop elektron penghantaran, manakala pencirian formulasi PNF menggunakan alat mikroskop inframerah jelmaan Fourier dan analisis termogravimetrik bagi menentukan sifat morfologi dan kestabilan terma masing-masing. Sifat-sifat reologi PNF dan HPAM diperoleh menerusi penggunaan alat Brookfield RST. Selain itu, tingkah laku PNF dan HPAM pada keadaan antara muka minyak-air telah dikaji menerusi penggunaan tensiometer Kruss. Di samping itu, kesan keterbasahan bendalir di dalam teras batu pasir dikaji dengan mengguna pakai alat sudut sentuh optik datafizik dengan perisian analisis imej terbina. Akhirnya, anjakan minyak berat di dalam teras batu pasir berkebolehtelapan sederhana pada keadaan reservoir telah dilaksana menerusi penggunaan alat banjiran teras HPHT. Keputusan ujikaji menunjukkan bahawa sifat rheologi bertambah baik berikutan penambahan NP, dengan degradasi molekul HPAM mengalami kerencatan. Pada larutan HPAM 2,000 ppm (27 mol % hidrolisis), kepekatan 0.1% berat NP menjadi pilihan optimum bagi NP Al_2O_3 dan SiO_2 yang mampu menghasilkan kelikatan tertinggi. PNFs memberikan prestasi kelikatan ricih yang lebih mantap pada kepekatan elektrolit yang berbeza dan suhu yang dikaji berikutan kesan pemerisaian. Selain itu, PNF mengurangkan IFT minyak berat kerana berlakunya penjerapan tidak berbalik NP pada antara muka minyak-air. Tambahan lagi, PNF boleh mengubah kebolehbasahan teras batu pasir daripada bersifat basah-minyak kepada basah-air berikutan kesan mekanisme struktur tekanan terpisah. Analisis mikroskop elektron imbasan pancaran medan dan analisis sinaran-x penyebaran tenaga mengesahkan berlakunya penjerapan nanopartikel pada teras batu pasir. Ujian anjakan minyak berat di dalam teras batu pasir berkebolehtelapan sederhana menunjukkan pertambahan perolehan minyak bila menggunakan PNF Al_2O_3 dan SiO_2 pada kepekatan optimum masing-masing, iaitu 10.6% dan 6.1% melebihi HPAM. Fenomena penurasan fizikal menurunkan kecekapan PNF pada kepekatan yang lebih tinggi. Gabungan sinergi NP dengan polimer berjaya memperbaiki sifat HPAM, lalu meningkatkan kecekapan sapuan tertingkat dan keberkesanan anjakan skala liang Kajian ini boleh memantapkan lagi pengetahuan dalam pengaplikasian nanoteknologi untuk EOR.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

Al_2O_3 - Aluminium oxide
AM - Acrylamide
APNF - Alumina polymeric nanofluid
cc - cubic centimetre
C - Carbon
Ca^{2+} - Calcium ions
CAC - Critical association concentration
CA_A - Advancing contact angle
CA_R - Receding contact angle
CO_2 - Carbon dioxide
cP - Centipoise
COO^- - Carboxylate group
CNC - Critical nanoparticle concentration
CSC - Critical salt concentration
DIW - Deionised water
DLS - Dynamic light scattering
DOH - Degree of hydrolysis
DPR - Disproportionate permeability reduction
DSNP - Dispersed silica nanoparticle
EDX - Energy-dispersive xray
EOR - Enhanced Oil Recovery
FAAS - Flame atomic absorption spectroscopy
FESEM - Field Emission Scanning Electron Microscope
FTIR - Fourier transform infrared microscopy
GO - Graphene oxide
GPC - Gel permeation chromatography
H - Hydrogen
HEC - Hydroxy ethyl cellulose
HPAM - Hydrolysed Polyacrylamide
HPHT - High Pressure High Temperature

HTHS - High Temperature and High Salinity
IFT - Interfacial tension
MWD - Molecular weight distribution
MMT - Montmorillonite
NaCl - Sodium Chloride
Na_2HCO_3 - Sodium hydrogen carbonate
NMR - Nuclear magnetic resonance
NP - Nanoparticle
OCA - Optical contact angle
OOIP - Original-oil-in-place
PAM - Polyacrylamide
PGN - Polymer grafted nanoparticle
PNF - Polymeric nanofluid
PNS - Polymeric nanofluid suspension
SAXS - Small-angle X-ray scattering
SEC - Size exclusion chromatography
SFB - Synthetic Formation Brine
SiO_2 - Silica or Silicon dioxide
SMCN - Surface modified clay nanoparticle
SPNF - Silica polymeric nanofluid
SSA - Specific Surface Area
SQUID - Super conducting quantum interference device
TEM - Transmission electron microscopy
TGA - Thermogravimetric analysis
XPS - X-ray photoelectron spectroscopy

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background of the Study

Despite contribution from renewable and other sources of energy, oil and gas has remained the major source of energy (Kumar et al., 2019). With increasing demand for energy and declining conventional sources of hydrocarbon, vast amount of previously abandoned heavy oil resource is being courted to support energy demand. Unlike conventional oil, production of heavy oil is more problematic due to its inherent properties. These include extremely low mobility (or immobility) because of its high viscosity, high heteroatom contents (e.g., asphaltenes, resins and heavy metals), and high carbon to hydrogen (C/H) ratio (i.e., aromaticity) (Guo et al., 2015). Hence, water flooding produces less than 30% of the original-oil-in-place (OOIP). To this end, thermal and non-thermal enhanced oil recovery (EOR) methods have been proffered and tested for heavy oil recovery applications. Thermal EOR are unsuitable for reservoirs with great depth and/or thin pay zones. Hence, non-thermal EOR methods, especially chemical EOR have received prodigious attention due to their ability to improve sweep and pore scale displacement efficiency (Yekeen et al., 2018).

Amongst all the non-thermal EOR techniques, polymer flooding, a chemical EOR method has been adjudged to be the most promising because of its high efficiency, technical and economic feasibilities, and lower capital cost (Pope, 2011). Apart from ensuring additional oil recovery from conventional crude oil reservoirs, polymer flooding is now been employed and preferred to improve production of medium to heavy oil reservoirs (Kamal et al., 2015). This is based on its ability to overcome the shortcomings of gas, thermal and in-situ combustion methods whose limitations are of technical, economical, and environmental concerns (Khalilinezhad et al., 2016). For example, the application of gas methods for low viscous oils is limited due to gravity override while the application of thermal techniques in thin and deep formations yields a low recovery factor because of severe heat losses to the overburden layers. Besides, large amount of steam required for thermal methods results in an increase in the operating costs and emission of greenhouse gas to the atmosphere (Saboorian-Jooybari et al., 2016).

The process of polymer flooding EOR technique involves adding high molecular weight water-soluble polymers to injection water. This results in an increase of the viscosity of the injected aqueous phase and leads to an improved recovery of bypassed and residual oil. The bypassed oil is recovered through an improvement in the mobility ratio of the displaced fluid while the residual oil is recovered through the viscoelastic nature of the polymers injected into the reservoir (Wegner, 2015). Polymer flooding has been successfully implemented in many oilfields either on a pilot scale or commercial scale for several decades. This includes the Daqing oil field in China, East Bodo Reservoir and Pelican Lake field in Canada, Marmul field in Oman, and Tambaredjo field, Suriname to mention just a few (Delamaide et al., 2014b; Sheng, 2013). In addition, polymer flooding has maintained its increasing importance to the current energy market (Li et al., 2017). The most notable contribution is the reported incremental oil production of up to 300,000 bbl/day from Daqing oil field in China (Cheraghian and Hendraningrat, 2016).

Hydrolysed polyacrylamide (HPAM), one of the synthetic polyacrylamide group, is the most often used polymer in EOR field applications because of its relatively low price, good viscosifying properties, and well-known physiochemical characteristics (Abidin et al., 2012; Pogaku et al., 2017; Wei, 2016). The implementation of HPAM during field operations is relatively easy and can significantly improve the oil recovery rate under standard reservoir conditions. However, HPAM is susceptible to harsh reservoir conditions such as high temperature and high salinity, which significantly affects their performance in EOR. At high salinity conditions and in the presence of monovalent and divalent ions (such as Na^+, Mg^{2+} and Ca^{2+}) in reservoir and formation brines, the opposite charges between the carboxylate group ($-$ COO^-) and the ions attract each other, thus leading to compression, distortion and precipitation of the polymer from solution. At high temperatures, degradation of the polymer occurs which results in viscosity reduction of the polymer (Sheng, 2011a; Wu et al., 2009). All these impose negative effects on the polymer's functionality in displacing oil, thus, lowering the economic viability of the flooding operation and ultimately reduce the polymer EOR process efficiency. From the above, it can be deduced that HPAM has deficiencies and need some modifications for EOR application in reservoirs to ensure maximal efficiency.

Hitherto, research for improvement of polymer flooding process has focussed on the development of new polymers for EOR process. Several attempts have been made to improve performance of polyacrylamide by developing salt and temperature tolerant polymers for EOR applications. To this end, many approaches have been used for the modification of polyacrylamide (PAM) (Khune et al., 1985; Sabhapondit et al., 2003). The most common method that has been applied to extend the application of acrylamide (AM) based polymers is copolymerisation of AM with suitable monomers that can increase the stiffness and rigidity of the polymer chain (Kamal et al., 2015). Though some of the new polymers formed from the modification process are found to be efficient in improving polymer rheological properties and adjudged to have good potential for EOR application, however, the formulated polymers have been deemed unsuitable due to economic reasons as they are expensive and will lead to an increase in the overall cost of the polymer flooding process (Kamal et al., 2015).

Advancement in research and new trends in polymer EOR involves the addition of nanoparticles (NP) to polymers used during flooding operations to improve polymer EOR process efficiency. Nanoparticles, also referred to as "engineered nano-material" are the collections of atom bonded together with sizes ranging from 1 nm to 100 nm (Cheraghian and Hendraningrat, 2016; Ragab, 2014). Generally, the application of nanoparticles for EOR have been found to possess the ability to improve the overall oil recovery factor due to their unique properties (Negin et al., 2016). They possess unique properties due to their small sizes and greater surface area per unit volume (Cheraghian and Hendraningrat, 2016). These properties include thermal properties like heat transfer, and property of mechanical strength like ultra-high strength of material (Bera and Belhaj, 2016).

The application of nanoparticles for improving polymer EOR has been hinged on its ability to enhance the polymeric fluid property, to make it more effective and efficient especially under harsh conditions of elevated temperatures and salinity (Yousefvand and Jafari, 2018). The most common nanoparticle utilised for use as polymeric nanofluid is the silicon dioxide nanoparticle, otherwise known silica (SiO_2). Investigating the influence of other nanoparticles especially metal oxide nanoparticle on polymeric fluid behaviour will be a good option for heavy oil recovery. In addition to their potential of enhancing polymeric fluids property, metal oxide nanoparticles have shown sterling abilities to reduce oil viscosity at typical reservoir conditions through aquathermolysis reactions.

Aluminium oxide nanoparticle, also known as alumina (Al_2O_3) is a metal oxide NP and is known to exhibit excellent properties during their use as nanofluid (Mallakpour and Khadem, 2015). They possess high thermal conductivity and can dissipate heat efficiently from fluids through Brownian motion (Rafati et al., 2016). Hence, fluids containing Al_2O_3 NP is less affected by temperature increase. Additionally, they have been reported to increase viscosity of injectant when used as nanodispersions. Also, Al_2O_3 NP is particularly known for its ability to cause viscosity reduction of heavy oil. Finally, they are low cost nanoparticles and environmentally friendly (Kedir et al., 2014; Kiruba et al., 2018). Hence, Al_2O_3 NP was investigated for its effect of HPAM polymeric fluid behaviour and compared with SiO_2 polymeric nanofluid and bare HPAM molecules at varying salinity and temperature representative of reservoir conditions. Besides, a mechanistic understanding of the polymeric nanofluids behaviour at pore scale which remains elusive in literature was ascertained.

1.2 Problem Statements

HPAM is the most widely used and preferred polymer during polymer EOR field applications because of its high viscosifying properties, resistance to bacteria attack, good water solubility, mobility control, low cost and availability in large quantities. However, the viscosity enhancement property of HPAM is susceptible and sensitive to harsh reservoir conditions such as elevated temperature, brine salinity, shear forces encountered in reservoirs (Goshtap Cheraghian, 2015; Hendraningrat et al., 2013). Recently, researchers have shown that appropriate addition of nanoparticles to polymer form novel materials which are beneficial for EOR applications. Nonetheless, the application of nanotechnology in polymer flooding have majorly investigated the use of inorganic SiO_2 NP and non-metallic oxide NP such as graphene oxide. Besides, research has also been focussed on investigating the effect of NP on rheological behaviour of the polymeric suspension to improve mobility ratio and sweep efficiency. Meanwhile, there exists only a few pieces of researches on PNF's behaviour at the pore scale, especially interfacial tension (IFT) and wettability alteration. Phenomenologically, an effective understanding of the microscopic behaviour of PNF's will help evaluate its ability to lower capillary pressure of trapped oil and boost oil recovery.

Additionally, most of the previous researches of oil displacement by PNF's were carried out in micromodel (Yousefvand and Jafari, 2015), glassbead pack (Abdullahi et al., 2018) and sandpack (Saha et al., 2018; Sharma et al., 2016). These porous media types are only symbolic and not synonymous with real reservoir cores as they do not account for the reservoir heterogeneity of oilfield applications. Moreover, while the process of such porous media (micromodel, glassbead and sandpack) preparation is apt, researchers ignore the possibility of fluid movement via the sidewalls of these porous media types. Fines migration/fluid channelling via the walls do take place during their use for oil displacement test and are unaccounted for even though they have consequential effect on the flooding results. Finally, oil displacement results reported in literatures were mostly at ambient conditions and/or for light and intermediate oil. Typical reservoir condition exists at variance with ambient conditions discussed in earlier researches. Besides, decline in conventional oil reserves has necessitated the need to explore available avenues to produce heavy oils to support the ever-increasing energy demand.

This work therefore seeks to extend the frontier of knowledge in PNF's application for heavy oil recovery by exploring, exploiting and evaluating the application of Al_2O_3 NP additive in sandstone cores at typical reservoir condition. As compared to other metal oxide NP such as Fe_2O_3, CuO, ZnO, TiO_2 and ZrO_2, Al_2O_3 NP is characterised with fixed oxidation states, hence, adjudged to have better stability. The influence of Al_2O_3 NP on the rheological properties of HPAM at typical reservoir field conditions (NaCl = 1 – 5 wt.%, Temperature = 60 – 90 °C, and Pressure = 2,500 psi) were evaluated and compared to those of well-researched SiO_2 PNF and bare HPAM molecules. Moreover, a mechanistic understanding of the pore scale displacement behaviour of PNF's in the presence of heavy oil which remains obscure in literature were elucidated.

1.3 Aim and Objectives of the Research

The aim of this research is to acquire a mechanistic understanding of the influence of nanoparticles on macroscopic and microscopic properties of oilfield polyacrylamide for heavy oil recovery applications. The objectives of this study are as follows:

i. To investigate the effect of the nanoparticles on rheological properties of oilfield polyacrylamide at typical reservoir salinity and temperature conditions.
ii. To quantify the IFT reduction and wettability alteration potential of the formulated polymeric nanofluids in the presence of heavy oil.
iii. To evaluate the incremental oil production after waterflooding due to the use of HPAM molecules and polymeric nanofluids for enhanced heavy oil recovery.

1.4 Scope and Limitation of the Study

The viscosity enhancement, rheological and other properties of HPAM polymer has been found to be influenced by factors such salinity, temperatures, degree of hydrolysis, pH, pressure and molecular weight. The scope of this research will be limited to addressing the main concerns imposed on HPAM flooding by salinity and temperature conditions. The polymer solution concentration was varied from 0.1–0.5 wt.% to determine the critical association concentration (CAC). At the polymer CAC, the effect of varying nanoparticle types (SiO_2 and Al_2O_3) and concentrations (0.01 – 1.0 wt.%) on the polymer solution viscosity was determined. To determine the effect of salinity on the HPAM and polymer nanofluids behaviour, the brine considered in this study is the monovalent sodium chloride (NaCl), which is the most commonly found salt in reservoirs. The salinity condition considered ranges from 1.0–5.0 wt.% while the temperature condition ranges from 27–90 °C. At the critical nanoparticle concentration (CNC), the rheology of the HPAM and polymeric nanofluids at fixed shear rate representative of reservoir condition and varying shear rate representative of fluid injection into the reservoir were determined using Brookfield RST Rheometer.

Subsequently, the IFT behaviour of HPAM and polymeric nanofluids in the presence of heavy oil (240 mPas). Additionally, the wettability behaviour of the HPAM and the formulated polymeric nanofluids in sandstone core was investigated using the contact angle method. The maximum temperature capacity of the Kruss tensiometer used for IFT measurement is 80 °C, hence, the IFT measurement of this study is limited to that temperature range. Finally, oil displacement experiments were carried out in mid-permeability sandstone cores with permeability ~200 mD. The confining pressure was fixed at 2500 psi representing high pressure witnessed in reservoirs at great depth. Fluid injectants into the core were at a flowrate of 0.2 mL/min. The temperature of the coreflooding process was fixed at 90 °C, representative of typical reservoir conditions. Meanwhile the salinity condition for the flooding process was fixed at critical salinity concentration (CSC). Overall, the process was monitored to evaluate the heavy oil recovery by varying injectant at the typical reservoir condition investigated, and more importantly to determine the mechanism of PNF efficiency.

1.5 Significance of the Study

To ensure a secure energy future, new methods are being developed through research and developments to overcome the limitations of the well-known conventional oil recovery methods. One of such methods is the application of nanotechnology to improve polymer flooding. New developments in polymer application for EOR involves the addition of nanoparticles to improve the rheological properties and polymer flooding characteristics of the process for oil recovery. This study makes a comparative analysis of polymeric nanofluids and bare polymer, and seek to understand their performance at the pore scale at typical reservoir conditions. The significance of this study is to extend the frontier of knowledge in chemical EOR through the mechanistic understanding of nanoparticle efficiency for application in polymer EOR. This study is beneficial for improving heavy oil recovery and will prove important in contributing to the ever-increasing energy demand.

1.6 Organisation of the Thesis

Chapter 1 gives a brief overview and background of enhanced oil recovery, explains the aim and objectives of the research, and the problem statement and gaps in existing knowledge of the area of research.

Chapter 2 outlines a detailed review of previous literature related to the theme of the research. It explains the concept of polymer flooding, the polymer types, the mechanism of polymer flooding, the deficiency of polymer flooding methods, and the synergic use of nanotechnology to overcome the shortcomings of polymer EOR.

Chapter 3 provides the procedure for polymer and polymeric nanofluids preparation and characterization. Besides, the materials, equipment and step-by-step guide for achieving the procedures of experiment as related to each objective was explained in detail.

Chapter 4 discusses the results and outcome of the nanoparticles, polymer and polymeric nanofluids characterization. Moreover, the performance evaluation and comparative analysis of the macroscopic and microscopic fluid behavior of the polymer and polymeric nanofluids were outlined. Finally, the mechanism of the fluid properties was explained.

Chapter 5 concludes the thesis with a summary of the main outcomes of the research and recommendations for further studies.

REFERENCES

Abbas, S., Sanders, A.W., Donovan, J.C., 2013. Applicability of Hydroxyethylcellulose Polymers for Chemical EOR, in: SPE-165311-MS, SPE Enhanced Oil Recovery Conference, 2-4 July, Kuala Lumpur, Malaysia. Society of Petroleum Engineers, pp. 1–9. https://doi.org/10.2118/165311-MS

Abdallah, W., Buckley, J.S., Carnegie, A., Edwards, J., Herold, B., Fordham, E., Graue, A., Habashy, T., Seleznev, N., Signe, C., Hussain, H., Montaron, B., Ziauddin, M., 2007. Fundamentals of Wettability. Oilf. Rev. 44–61. https://doi.org/10.6028/NBS.IR.78-1463

Abdullahi, M.B., Rajaei, K., Junin, R., Bayat, A.E., 2018. Appraising the impact of metal-oxide nanoparticles on rheological properties of HPAM in different electrolyte solutions for enhanced oil recovery. J. Pet. Sci. Eng. 1–15. https://doi.org/https://doi.org/10.1016/j.petrol.2018.09.013

Abidin, A.Z., Puspasari, T., Nugroho, W.A., 2012. Polymers for Enhanced Oil Recovery Technology. Procedia Chem. 4, 11–16. https://doi.org/10.1016/j.proche.2012.06.002

Afolabi, R.O., 2015. Effect of Surfactant and Hydrophobe Content on the Rheology of Poly (acrylamide- co - N -dodecylacrylamide) for Potential Enhanced Oil Recovery Application. Am. J. Polym. Sci. 5, 41–46. https://doi.org/10.5923/j.ajps.20150502.02

Afolabi, R.O., Yusuf, E.O., 2019. Nanotechnology and global energy demand: challenges and prospects for a paradigm shift in the oil and gas industry. J. Pet. Explor.Prod.Technol. 9, 1423–1441. https://doi.org/10.1007/s13202-018-0538-0

Afsharpoor, A., Balhoff, M.T., Bonnecaze, R., Huh, C., 2012. CFD modeling of the effect of polymer elasticity on residual oil saturation at the pore-scale. J. Pet. Sci. Eng. 94, 79–88. https://doi.org/10.1016/j.petrol.2012.06.027

Agi, A., Junin, R., Abbas, A., Gbadamosi, A., Azli, N.B., 2019a. Effect of dynamic spreading and the disperse phase of crystalline starch nanoparticles in enhancing oil recovery at reservoir condition of a typical sarawak oil field. Appl. Nanosci. 1–17. https://doi.org/10.1007/s13204-019-01102-5

Agi, A., Junin, R., Gbadamosi, A., 2018. Mechanism governing nanoparticle flow behaviour in porous media: insight for enhanced oil recovery applications. Int. Nano Lett. 8, 1–29. https://doi.org/10.1007/s40089-018-0237-3

Agi, A., Junin, R., Gbadamosi, A., Abbas, A., Azli, N.B., Oseh, J., 2019b. Influence of nanoprecipitation on crystalline starch nanoparticle formed by ultrasonic assisted weak-acid hydrolysis of cassava starch and the rheology of their solutions. Chem. Eng. Process. - Process Intensif. 142, 107556.

Akbari, S., Mahmood, S.M., Tan, I.M., Ghaedi, H., Ling, O.L., 2017. Assessment of Polyacrylamide Based Co-Polymers Enhanced by Functional Group Modifica tions with Regards to Salinity and Hardness. Polymers (Basel). 9. https://doi.org /10.3390/polym9120647

Akstinat, M.H., 1980. Polymers For Enhanced Oil Recovery In Reservoirs Of Extremely High Salinities And High Temperatures, in: SPE-8979-MS, Oilfield and Geothermal Chemistry Symposium, 28-30 May, Stanford, California. Society of Petroleum Engineers, pp. 33–45. https://doi.org/10.2118/8979-MS

Al-Anssari, S., Wang, S., Barifcani, A., Lebedev, M., Iglauer, S., 2017. Effect of temperature and SiO_2 nanoparticle size on wettability alteration of oil-wet cal cite. Fuel 206, 34–42. https://doi.org/https://doi.org/10.1016/j.fuel.2017.05. 077

Al-saadi, F.S., Al-amri, B.A., Al Nofli, S.M., Van Wunnik, J.N.M., Jaspers, H.F., Al Harthi, S., Shuaili, K., Cherukupalli, P.K., Chakravarthi, R., 2012. Polymer Flooding in a Large Field in South Oman - Initial Results and Future Plans, in: SPE-154665-MS, Presented at SPE EOR Conference at Oil and Gas West Asia, 16-18 April, Muscat, Oman. Society of Petroleum Engineers, pp. 1–7. https://doi.org/10.2118/154665-MS

Al Otaibi, F.M., Kokal, S.L., Chang, Y., AlQahtani, J.F., AlAbdulwahab, A.M., 2013. Gelled Emulsion of CO-Water-Nanoparticles, in: Paper SPE-166072–MS, Presented at SPE Annual Technical Conference and Exhibition, 30 September-2 October, New Orleans, Louisiana, USA. Society of Petroleum Engineers, pp. 1–13. https://doi.org/10.2118/166072-MS

Alhammadi, A.M., AlRatrout, A., Singh, K., Bijeljic, B., Blunt, M.J., 2017. In situ characterization of mixed-wettability in a reservoir rock at subsurface conditions. Sci. Rep. 7, 10753. https://doi.org/10.1038/s41598-017-10992-w

Ali, J.A., Kolo, K., Manshad, A.K., Stephen, K.D., 2019. Potential application of low-salinity polymeric-nanofluid in carbonate oil reservoirs: IFT reduction, wettability alteration, rheology and emulsification characteristics. J. Mol. Liq. 1–32. https://doi.org/https://doi.org/10.1016/j.molliq.2019.04.053

Aluhwal, O.K.H., 2008. Simulation study of improving oil recovery by polymer flooding in a malaysian reservoir. A thesis submited to the department of petroleum engineering, Universiti Teknologi Malaysia.

Ameli, F., Moghbeli, M.R., Alashkar, A., 2019. On the effect of salinity and nano-particles on polymer flooding in a heterogeneous porous media: Experimental and modeling approaches. J. Pet. Sci. Eng. 174, 1152–1168. https://doi.org/https://doi.org/10.1016/j.petrol.2018.12.015

Arjmand, O., Zarekhafri, A., Mousavi, S.M., 2015. Introduction of Cotton Gum as a Natural Polymer. Int. J. Chem. Pet. Sci. 4, 26–33.

Bayat, A., 2015. Effective parameters of metal oxide nanoparticles transportation through porous media packs for Enhanced Oil Recovery. A thesis submitted to the Department of Petroleum Engineering, Universiti Teknologi Malaysia.

Bera, A., Belhaj, H., 2016. Application of nanotechnology by means of nanoparticles and nanodispersions in oil recovery - A comprehensive review. J. Nat. Gas Sci. Eng. 34, 1284–1309. https://doi.org/10.1016/j.jngse.2016.08.023

Bera, A., S, K., Ojha, K., Kumar, T., Mandal, A., 2012. Mechanistic Study of Wettability Alteration of Quartz Surface Induced by Nonionic Surfactants and Interaction between Crude Oil and Quartz in the Presence of Sodium Chloride Salt. Energy & Fuels 26, 3634–3643. https://doi.org/10.1021/ef300472k

Bessaies-Bey, H., Fusier, J., Harrisson, S., Destarac, M., Jouenne, S., Passade-Boupat, N., Lequeux, F., d'Espinose de Lacaillerie, J.-B., Sanson, N., 2018. Impact of polyacrylamide adsorption on flow through porous siliceous materials: State of the art, discussion and industrial concern. J. Colloid Interface Sci. 531, 693–704. https://doi.org/https://doi.org/10.1016/j.jcis.2018.07.103

Bila, A., Stensen, J.Å., Torsæter, O., 2019. Experimental Investigation of Polymer-Coated Silica Nanoparticles for Enhanced Oil Recovery. Nanomaterials 9, 822. https://doi.org/10.3390/nano9060822

Chandran, S., Begam, N., Padmanabhan, V., Basu, J.K., 2014. Confinement enhances dispersion in nanoparticle–polymer blend films. Nat. Commun. 5, 3697.

Chauveteau, G., Zaitoun, A., 1981. Basic rheological behavior of xanthan polysaccharide solutions in porous media: Effect of pore size and polymer concentration, in: Proceedings of the First European Symposium on Enhanced Oil Recovery, Bournemouth, England, Society of Petroleum Engineers, Richardson, TX. pp. 197–212.

Cheraghian, G., 2016a. Application of nano-fumed silica in heavy oil recovery. Pet. Sci. Technol. 34, 12–18. https://doi.org/10.1080/10916466.2015.1114497

Cheraghian, G., 2016b. Effect of nano titanium dioxide on heavy oil recovery during polymer flooding. Pet. Sci. Technol. 34, 633–641. https://doi.org/10.1080/10916466.2016.1156125

Cheraghian, Goshtap, 2015. Effects of nanoparticles on wettability : A review on applications of nanotechnology in the enhanced Oil recovery. Int. J. Nano Dimens. 6, 443–452. https://doi.org/10.7508/ijnd.2015.05.001

Cheraghian, Goshtasp, 2015. An Experimental Study of Surfactant Polymer for Enhanced Heavy Oil Recovery Using a Glass Micromodel by Adding Nanoclay. Pet. Sci. Technol. 33, 1410–1417.

Cheraghian, G., Hendraningrat, L., 2016. A review on applications of nanotechnology in the enhanced oil recovery part A: effects of nanoparticles on interfacial tension. Int. Nano Lett. 6, 129–138.

Cheraghian, G., Khalili Nezhad, S.S., Kamari, M., Hemmati, M., Masihi, M., Bazgir, S., 2014. Adsorption polymer on reservoir rock and role of the nanoparticles, clay and SiO2. Int.NanoLett. 4, 114. https://doi.org/10.1007/s40089-014-0114-7

Cheraghian, G., Khalilinezhad, S.S., 2015. Effect of Nanoclay on Heavy Oil Recovery During Polymer Flooding. Pet. Sci. Technol. 33, 999–1007. https://doi.org/10.1080/10916466.2015.1014962

Choi, B., Jeong, M.S., Lee, K.S., 2014. Temperature-dependent viscosity model of HPAM polymer through high-temperature reservoirs. Polym. Degrad. Stab. 110, 225–231. https://doi.org/https://doi.org/10.1016/j.polymdegradstab.2014.09.006

Chul, J.J., Ke, Z., Hyun, C.B., Jin, C.H., 2012. Rheology and polymer flooding characteristics of partially hydrolyzed polyacrylamide for enhanced heavy oil re covery. J. Appl. Polym. Sci. 127, 4833–4839. https://doi.org/10.1002/app.38070

Clarke, A., Howe, A.M., Mitchell, J., Staniland, J., Hawkes, L.A., 2016. How Viscoelastic-Polymer Flooding Enhances Displacement Efficiency. SPE-174654-PA, Soc. Pet. Eng. J. 21, 675–687. https://doi.org/10.2118/174654-PA

Clay, T.D., Menzie, D.E., 1966. The Effect of Polymer Additives on Oil Recovery In Conventional Waterflooding, in: SPE Four Corners Regional Meeting, 9-10 September, Farmington, New Mexico. SPE 1670. Society of Petroleum Engineers, pp. 1–6. https://doi.org/10.2118/1670-MS

Clemens, T., Deckers, M., Kornberger, M., Gumpenberger, T., Zechner, M., 2013. Polymer Solution Injection - Near Wellbore Dynamics and Displacement Efficiency, Pilot Test Results, Matzen Field, Austria., in: SPE-164904-MS, Presented at EAGE Annual Conference & Exhibition Incorporating SPE Europec, 10-13 June, London, UK. Society of Petroleum Engineers, pp. 1–13. https://doi.org/10.2118/164904-MS

Corredor-Rojas, L.M., Hemmati-Sarapardeh, A., Husein, M.M., Dong, M., Maini, B.B., 2018. Rheological Behavior of Surface Modified Silica Nanoparticles Dispersed in Partially Hydrolyzed Polyacrylamide and Xanthan Gum Solutions: Experimental Measurements, Mechanistic Understanding, and Model Development. Energy & Fuels 32, 10628–10638. https://doi.org/10.1021/acs.energyfuels.8b02658

Corredor, Laura M, Aliabadian, E., Husein, M., Chen, Z., Maini, B., Sundararaj, U., 2019. Heavy oil recovery by surface modified silica nanoparticle/HPAM nanofluids. Fuel 252, 622–634. https://doi.org/https://doi.org/10.1016/j.fuel.2019.04.145

Corredor, Laura M., Husein, M.M., Maini, B.B., 2019. Impact of PAM-Grafted Nanoparticles on the Performance of Hydrolyzed Polyacrylamide Solutions for Heavy Oil Recovery at Different Salinities. Ind. Eng. Chem. Res. 58, 9888–9899. https://doi.org/10.1021/acs.iecr.9b01290

Dang, T.Q.C., Chen, Z., Nguyen, T.B.N., Bae, W., 2015. Rheological Modeling and Numerical Simulation of HPAM Polymer Viscosity in Porous Media. Energy Sources, Part A Recover. Util. Environ. Eff. 37, 2189–2197. https://doi.org/10.1080/15567036.2011.624156

Delamaide, E., Bazin, B., Rousseau, D., Degre, G., 2014a. Chemical EOR for Heavy Oil: The Canadian Experience, in: SPE-169715-MS, Presented at SPE EOR Conference at Oil and Gas West Asia, 31 Mar-2 April, Muscat, Oman, pp. 1–31.

Delamaide, E., Zaitoun, A., Renard, G., Tabary, R., 2014b. Pelican Lake Field: First Successful Application of Polymer Flooding In a Heavy-Oil Reservoir. Soc. Pet. Eng. J. SPE-165234-PA 17, 1–22. https://doi.org/10.2118/165234-PA

Détling, K.D., 1944. Process of Recovering Oil from Oil Sands. https://doi.org/US2341500 A

Drumeanu, A.C., 2017. Some considerations concerning four-ball machine testing of the polyacrylamide solutions, in: IOP Conference Series: Materials Science and Engineering. pp. 1–7. https://doi.org/10.1088/1757-899X/174/1/012040

Du, Y., Guan, L., 2004. Field-scale Polymer Flooding: Lessons Learnt and Experiences Gained During Past 40 Years, in: SPE-91787-MS, Presented at SPE International Petroleum Conference in Mexico, 7-9 November, Puebla Pue. Mexico. Society of Petroleum Eng, pp. 1–6. https://doi.org/10.2118/917 87-MS

Ebnesajjad, S., 2014. Chapter 4 - Surface and Material Characterization Techniques, in: Ebnesajjad, S. (Ed.), Surface Treatment of Materials for Adhesive Bonding (Second Edition). William Andrew Publishing, Oxford, pp. 39–75. https://doi.org/https://doi.org/10.1016/B978-0-323-26435-8.00004-6

El-Diasty, A.I., Ragab, A.M.S., 2013. Applications of Nanotechnology in the Oil & Gas Industry: Latest Trends Worldwide & Future Challenges in Egypt, in: SPE-164716-MS, Presented at North Africa Technical Conference and Exhibition, 15-17 April, Cairo, Egypt. Society of Petroleum Engineers, pp. 1–13. https://doi.org/10.2118/164716-MS

Esfandyari Bayat, A., Junin, R., Samsuri, A., Piroozian, A., Hokmabadi, M., 2014. Impact of Metal Oxide Nanoparticles on Enhanced Oil Recovery from Limestone Media at Several Temperatures. Energy & Fuels 28, 6255–6266.

Esmaeilzadeh, P., Bahramian, A., Fakhroueian, Z., 2011. Adsorption of Anionic, Cationic and Nonionic Surfactants on Carbonate Rock in Presence of ZrO2 Nanoparticles. Phys. Procedia 22, 63–67.

Fakoya, M.F., Shah, S.N., 2017. Emergence of nanotechnology in the oil and gas industry: Emphasis on the application of silica nanoparticles. Petroleum 1–15. https://doi.org/10.1016/j.petlm.2017.03.001

Gbadamosi, A.O., Junin, R., Manan, M.A., Agi, A., Yusuff, A.S., 2019a. An overview of chemical enhanced oil recovery: recent advances and prospects. Int. Nano Lett. 1–32. https://doi.org/10.1007/s40089-019-0272-8

Gbadamosi, A.O., Junin, R., Manan, M.A., Yekeen, N., Agi, A., Oseh, J.O., 2018. Recent Advances and Prospects in Polymeric Nanofluids Application for Enhanced Oil Recovery. J. Ind. Eng. Chem. 1–16. https://doi.org/https://doi.org/ 10.1016/j.jiec.2018.05.020

Gbadamosi, A.O., Junin, R., Manan, M.A., Yekeen, N., Augustine, A., 2019b. Hybrid suspension of polymer and nanoparticles for enhanced oil recovery. Polym. Bull. 1–38. https://doi.org/10.1007/s00289-019-02713-2

Giraldo, J., Benjumea, P., Lopera, S., Cortés, F.B., Ruiz, M.A., 2013. Wettability Alteration of Sandstone Cores by Alumina-Based Nanofluids. Energy & Fuels 27, 3659–3665. https://doi.org/10.1021/ef4002956

Giraldo, L.J., Giraldo, M.A., Llanos, S., Maya, G., Zabala, R.D., Nassar, N.N., Franco, C.A., Alvarado, V., Cortés, F.B., 2017. The effects of SiO2 nanoparticles on the thermal stability and rheological behavior of hydrolyzed polyacrylamide based polymeric solutions. J. Pet. Sci. Eng. 159, 841–852. https://doi.org/https://doi.org/10.1016/j.petrol.2017.10.009

Gleasure, R.W., 1990. An Experimental Study of Non-Newtonian Polymer Rheology Effects on Oil Recovery and Injectivity. SPE-17648-PA, Soc. Pet. Eng. 5, 481–486. https://doi.org/10.2118/17648-PA

Godwin Uranta, K., Rezaei-Gomari, S., Russell, P., Hamad, F., 2018. Studying the Effectiveness of Polyacrylamide (PAM) Application in Hydrocarbon Reservoirs at Different Operational Conditions. Energies 11. https://doi.org/10.3390/en11092201

Gogarty, W.B., 1967. Mobility Control With Polymer Solutions. Solut. Soc. Pet. Eng. 7, 161–173. https://doi.org/10.2118/1566-B

Guo, K., Li, H., Yu, Z., 2016. In-situ heavy and extra-heavy oil recovery: A review. Fuel 185, 886–902. https://doi.org/https://doi.org/10.1016/j.fuel.2016.08.047

Guo, K., Li, H., Yu, Z., 2015. Metallic Nanoparticles for Enhanced Heavy Oil Recovery: Promises and Challenges. Energy Procedia 75, 2068–2073. https://doi.org/https://doi.org/10.1016/j.egypro.2015.07.294

Haghtalab, A., Kamali, M.J., Shahrabadi, A., Golghanddashti, H., 2015. Investigation of the Precipitation of Calcium Sulfate in Porous Media: Experimental and Mathematical Modeling. Chem. Eng. Commun. 202, 1221–1230. https://doi.org/10.1080/00986445.2014.913583

Hanemann, T., Szabó, D.V., 2010. Polymer-nanoparticle composites: From synthesis to modern applications, Materials. https://doi.org/10.3390/ma3063468

Haruna, M.A., Pervaiz, S., Hu, Z., Nourafkan, E., Wen, D., 2019. Improved rheology and high-temperature stability of hydrolyzed polyacrylamide using graphene oxide nanosheet. J. Appl. Polym. Sci. 0, 47582 (1–13).

He, Z., Alexandridis, P., 2015. Nanoparticles in ionic liquids: interactions and organization. Phys. Chem. Chem. Phys. 17, 18238–18261. https://doi.org/10.1039/C5CP01620G

Hendraningrat, L., Li, S., Torsæter, O., 2013. A coreflood investigation of nanofluid enhanced oil recovery. J. Pet. Sci. Eng. 111, 128–138. https://doi.org/10.1016/j.petrol.2013.07.003

Hryc, A., Hochenfellner, F., Paponi, H., Puliti, R., Gerlero, T., 2013. Design and Execution of a Polymer Injection Pilot in Argentina, in: SPE-166078-MS, Presented at SPE Annual Technical Conference and Exhibition, 30 September-2 October, New Orleans, Louisiana, USA. Society of Petroleum Engineers, pp. 1–15. https://doi.org/10.2118/166078-MS

Hu, Z., Haruna, M., Gao, H., Nourafkan, E., Wen, D., 2017. Rheological Properties of Partially Hydrolyzed Polyacrylamide Seeded by Nanoparticles. Ind. Eng. Chem. Res. 56, 3456–3463. https://doi.org/10.1021/acs.iecr.6b05036

Huh, C., Pope, G.A., 2008. Residual Oil Saturation from Polymer Floods: Laboratory Measurements and Theoretical Interpretation, in: SPE-113417-MS, Presented at SPE Symposium on Improved Oil Recovery, 20-23 April, Tulsa, Oklahoma, USA. Society of Petroleum Engineers, pp. 744–764. https://doi.org/10.2118/113417-MS

Jang, H.Y., Zhang, K., Chon, B.H., Choi, H.J., 2015. Enhanced oil recovery perform ance and viscosity characteristics of polysaccharide xanthan gum solution. J. Ind. Eng. Chem. 21, 741–745. https://doi.org/https://doi.org/10.1016 /j.jiec.2014 .04.005

Kamal, M.S., Hussein, I.A., Sultan, A.S., 2017. Review on Surfactant Flooding: Phase Behavior, Retention, IFT, and Field Applications. Energy & Fuels 31, 7701–7720. https://doi.org/10.1021/acs.energyfuels.7b00353

Kamal, M.S., Sultan, A.S., Al-Mubaiyedh, U.A., Hussein, I.A., 2015. Review on Polymer Flooding: Rheology, Adsorption, Stability, and Field Applications of Various Polymer Systems. Polym. Rev. 55, 491–530. https://doi.org/10.1080/15583724.2014.982821

Karimi, A., Fakhroueian, Z., Bahramian, A., Pour Khiabani, N., Darabad, J.B., Azin, R., Arya, S., 2012. Wettability Alteration in Carbonates using Zirconium Oxide Nanofluids: EOR Implications. Energy & Fuels 26, 1028–1036. https://doi.org/10.1021/ef201475u

Kawaguchi, M., 1994. Rheological properties of silica suspensions in polymer solutions. Adv. Colloid Interface Sci. 53, 103–127. https://doi.org/10.1016/ 0001-8686(94)00214-2

Kedir, A.S., Seland, J.G., Skauge, A., Skauge, T., 2014. Nanoparticles for Enhanced Oil Recovery: Phase Transition of Aluminum-Cross-Linked Partially Hydrolyzed Polyacrylamide under Low-Salinity Conditions by Rheology and Nuclear Magnetic Resonance. Energy & Fuels 28, 2948–2958. https://doi.org/10.1021/ef5000694

Khalilinezhad, S.S., Cheraghian, G., Karambeigi, M.S., Tabatabaee, H., Roayaei, E., 2016. Characterizing the Role of Clay and Silica Nanoparticles in Enhanced Heavy Oil Recovery During Polymer Flooding. Arab. J. Sci. Eng. 41, 2731–2750. https://doi.org/10.1007/s13369-016-2183-6

Khune, G.D., Donaruma, L.G., Hatch, M.J., Kilmer, N.H., Shepitka, J.S., Martin, F.D., 1985. Modified acrylamide polymers for enhanced oil recovery. J. Appl. Polym. Sci. 30, 875–885. https://doi.org/10.1002/app.1985.070300234

Kiruba, R., Vinod, S., Zaibudeen, A.W., Solomon, R.V., Philip, J., 2018. Stability and Rheological properties of hybrid γ-Al2O3 Nanofluids with cationic polyelectrolyte additives. Colloids Surfaces A Physicochem. Eng. Asp. https://doi.org/https://doi.org/10.1016/j.colsurfa.2018.06.044

Kondiparty, K., Nikolov, A., Wu, S., Wasan, D., 2011. Wetting and Spreading of Nanofluids on Solid Surfaces Driven by the Structural Disjoining Pressure: Statics Analysis and Experiments. Langmuir 27, 3324–3335. https://doi.org/10.1021/la104204b

Kotlar, H.K., Selle, O., Torsaeter, O., 2007. Enhanced Oil Recovery by COMB Flow: Polymer Floods Revitalized, in: SPE-106421-MS, Presented at International Symposium on Oilfield Chemistry, 28 February-2 March, Houston, Texas, U.S.A. Society of Petroleum Engineers, pp. 1–6. https://doi.org/10.2118/106421-MS

Krishnamoorti, R., 2006. Extracting the Benefits of Nanotechnology for the Oil Industry. J. Pet. Technol. 58, 24–25. https://doi.org/10.2118/1106-0024-JPT

Kumar, M.S., Pallab, G., Kanti, S.T., 2019. Role of chemical additives and their rheological properties in enhanced oil recovery. Rev. Chem. Eng. https://doi.org/10.1515/revce-2018-0033

Kumar, N., Gaur, T., Mandal, A., 2017. Characterization of SPN Pickering emulsions for application in enhanced oil recovery. J. Ind. Eng. Chem. 54, 304–315. https://doi.org/https://doi.org/10.1016/j.jiec.2017.06.005

Kumar, R.S., Sharma, T., 2018. Stability and rheological properties of nanofluids stabilized by SiO2 nanoparticles and SiO2-TiO2 nanocomposites for oilfield applications. Colloids Surfaces A Physicochem. Eng. Asp. 539, 171–183. https://doi.org/https://doi.org/10.1016/j.colsurfa.2017.12.028

Kumar, S., 2015. Structural studies of nanoparticles interactions with different macromolecules.

Kumar, S., Aswal, V.K., Kohlbrecher, J., 2016. Small-Angle Neutron Scattering Study of Interplay of Attractive and Repulsive Interactions in Nanoparticle–Polymer System. Langmuir 32, 1450–1459. https://doi.org/10.1021/acs.langmuir.5b03998

Kumar, S., Ray, D., Aswal, V.K., Kohlbrecher, J., 2014. Structure and interaction in the polymer-dependent reentrant phase behavior of a charged nanoparticle solution. Phys. Rev. E - Stat. Nonlinear, Soft Matter Phys. 90, 1–10. https://doi.org/10.1103/PhysRevE.90.042316

Lai, N., Guo, X., Zhou, N., Xu, Q., 2016a. Shear Resistance Properties of Modified Nano-SiO2/AA/AM Copolymer Oil Displacement Agent. Energies 9, 1037. https://doi.org/10.3390/en9121037

Lai, N., Zhang, Y., Xu, Q., Zhou, N., Wang, H., Ye, Z., 2016b. A water-soluble hyperbranched copolymer based on a dendritic structure for low-to-moderate permeability reservoirs. RSC Adv. 6, 32586–32597. https://doi.org/10.1039/C6RA06397G

Lakhova, A., Petrov, S., Ibragimova, D., Kayukova, G., Safiulina, A., Shinkarev, A., Okekwe, R., 2017. Aquathermolysis of heavy oil using nano oxides of metals. J. Pet. Sci. Eng. 153, 385–390. https://doi.org/https://doi.org/10.1016/j.petrol.2017.02.015

Lam, C., Jefferis, S.A., 2017. Introduction to polymers and polymer fluids, in: Polymer Support Fluids in Civil Engineering. pp. 29–55. https://doi.org/10.1680/psfce.57869.029

Lam, C., Martin, P.J., Jefferis, S.A., 2015. Rheological Properties of PHPA Polymer Support Fluids. J. Mater. Civ. Eng. 27, 04015021. https://doi.org/10.1061/(asce)mt.1943-5533.0001252

Le, N.Y.T., Pham, D.K., Le, K.H., Nguyen, P.T., 2011. Design and screening of synergistic blends of SiO_2 nanoparticles and surfactants for enhanced oil recovery in high-temperature reservoirs. Adv. Nat. Sci. Nanosci. Nanotechnol. 2, 35013.

Levitt, D., Pope, G.A., 2008. Selection and Screening of Polymers for Enhanced-Oil Recovery, in: SPE-113845-MS, Presented at SPE Symposium on Improved Oil Recovery, 20-23 April, Tulsa, Oklahoma, USA. Society of Petroleum Engineers, pp. 1–18. https://doi.org/10.2118/113845-MS

Li, Q., Pu, W., Wei, B., Jin, F., Li, K., 2017. Static adsorption and dynamic retention of an anti-salinity polymer in low permeability sandstone core. J. Appl. Polym. Sci. 134, 44487–44488. https://doi.org/10.1002/app.44487

Li, S., Hendraningrat, L., Torsaeter, O., 2013. Improved Oil Recovery by Hydrophilic Silica Nanoparticles Suspension: 2-Phase Flow Experimental Studies, in: IPTC-16707-MS, Presented at International Petroleum Technology Conference, 26-28 March, Beijing, China. International Petroleum Technology Conference, pp. 1–15. https://doi.org/10.2523/IPTC-16707-MS

Li, S., Torsæter, O., 2014. An Experimental Investigation of EOR Mechanisms for Nanoparticles Fluid in Glass Micromodel, in: International Symposium of the Society of Core Analysts (Avignon / France). pp. 1–12. https://doi.org/10.13140 /RG.2.1.4181.3604

Lim, S., Zhang, H., Wu, P., Nikolov, A., Wasan, D., 2016. The dynamic spreading of nanofluids on solid surfaces – Role of the nanofilm structural disjoining pressure. J. Colloid Interface Sci. 470, 22–30.

Lima, M.C.F.S., do Amparo, S.Z., Ribeiro, H., Soares, A.L., Viana, M.M., Seara, L.M., Paniago, R.M., Silva, G.G., Caliman, V., 2016. Aqueous suspensions of carbon black with ethylenediamine and polyacrylamide-modified surfaces: Applications for chemically enhanced oil recovery. Carbon N. Y. 109, 290–299. https://doi.org/https://doi.org/10.1016/j.carbon.2016.08.021

Lindley, J., 2011. Chemical Flooding (Polymer). An online material available at: http://www.netl.doe.gov. Assessed on 30/07.2017

Liu, J., Adegbesan, K.O., Bai, J., 2012. Suffield Area, Alberta, Canada - Caen Polymer Flood Pilot Project, in: SPE-157796-MS, SPE Heavy Oil Conference Canada, 12-14 June, Calgary, Alberta, Canada. Society of Petroleum Engineers, pp. 1–10. https://doi.org/10.2118/157796-MS

Liu, Q., Dong, M., Ma, S., Tu, Y., 2007. Surfactant enhanced alkaline flooding for Western Canadian heavy oil recovery. Colloids Surfaces A Physicochem. Eng. Asp. 293, 63–71. https://doi.org/https://doi.org/10.1016/j.colsurfa.2006.07.013

Llanos, S., Giraldo, L.J., Santamaria, O., Franco, C.A., Cortés, F.B., 2018. Effect of Sodium Oleate Surfactant Concentration Grafted onto SiO2 Nanoparticles in Polymer Flooding Processes. ACS Omega 3, 18673–18684. https://doi.org/10.1021/acsomega.8b02944

Loppinet, A., Iakovlev, S., Glenat, P., 1997. Five years of injection of hydroxyethylcellulose : An ecological pure product for enhanced oil recovery in the field of Romashkino, in: Offshore Europe 97. Conference. pp. 39–43.

Lu, D.T., Liu, H., Zhu, Y.B., Wang, F.C., Chen, J., Fan, J.C., Wu, H.A., 2018. Molecular mechanism of viscoelastic polymer enhanced oil recovery in nanopores. R. Soc. Open Sci. 5, 180076. https://doi.org/10.1098/rsos.180076

Maghzi, A., Kharrat, R., Mohebbi, A., Ghazanfari, M.H., 2014. The impact of silica nanoparticles on the performance of polymer solution in presence of salts in polymer flooding for heavy oil recovery. Fuel 123, 123–132. https://doi.org/10.1016/j.fuel.2014.01.017

Maghzi, A., Mohebbi, A., Kharrat, R., Ghazanfari, M.H., 2013. An Experimental Investigation of Silica Nanoparticles Effect on the Rheological Behavior of Polyacrylamide Solution to Enhance Heavy Oil Recovery. Pet. Sci. Technol. 31, 500–508. https://doi.org/10.1080/10916466.2010.518191

Maghzi, A., Mohebbi, A., Kharrat, R., Ghazanfari, M.H., 2011. Pore-Scale Monitoring of Wettability Alteration by Silica Nanoparticles During Polymer Flooding to Heavy Oil in a Five-Spot Glass Micromodel. Transp. Porous Media 87, 653–664.

Mallakpour, S., Khadem, E., 2015. Recent development in the synthesis of polymer nanocomposites based on nano-alumina. Prog. Polym. Sci. 51, 74–93. https://doi.org/https://doi.org/10.1016/j.progpolymsci.2015.07.004

Mandal, A., 2015. Chemical flood enhanced oil recovery : a review. Int. J. Oil, Gas Coal Technol. 9, 241–264.

Mandal, A., Samanta, A., Ojha, K., 2013. Mobility control and enhanced oil recovery using partially hydrolysed polyacrylamide (PHPA). Int. J. Oil Gas Coal Technol. 6, 245–258. https://doi.org/10.1504/IJOGCT.2013.052236

Maurya, N.K., Kushwaha, P., Mandal, A., 2017. Studies on interfacial and rheological properties of water soluble polymer grafted nanoparticle for application in enhanced oil recovery. J. Taiwan Inst. Chem. Eng. 70, 319–330. https://doi.org/https://doi.org/10.1016/j.jtice.2016.10.021

Maurya, N.K., Mandal, A., 2016. Studies on behavior of suspension of silica nano-particle in aqueous polyacrylamide solution for application in enhanced oil recovery. Pet. Sci. Technol. 34, 429–436. https://doi.org/10.1080/10916466.2016.1145693

Meyers, J.J., Pitts, M.J., Wyatt, K., 1992. Alkaline-Surfactant-Polymer Flood of the West Kiehl, Minnelusa Unit, in: SPE-24144-MS, Presented at SPE/DOE Enhanced Oil Recovery Symposium, 22-24 April, Tulsa, Oklahoma. Society of Petroleum Engineers, pp. 423–433. https://doi.org/10.2118/24144-MS

Mishra, S., Bera, A., Mandal, A., Mishra, S., Bera, A., Mandal, A., 2014. Effect of Polymer Adsorption on Permeability Reduction in Enhanced Oil Recovery. J. Pet. Eng. 2014, 1–9. https://doi.org/10.1155/2014/395857

Moghadam, A.M., Mahsa, B.S., 2018. Enhancing hydrocarbon productivity via wettability alteration: a review on the application of nanoparticles. Rev. Chem. Eng. https://doi.org/10.1515/revce-2017-0105

Mogollon, J.L., Lokhandwala, T., 2013. Rejuvenating Viscous Oil Reservoirs by Polymer Injection: Lessons Learned in the Field, in: SPE-165275-MS, Presented SPE Enhanced Oil Recovery Conference, 2-4 July, Kuala Lumpur, Malaysia. Society of Petroleum Engineers, pp. 1–12. https://doi.org/10.2118/165275-MS

Mohammed, M., Babadagli, T., 2015. Wettability alteration: A comprehensive review of materials/methods and testing the selected ones on heavy-oil containing oil-wet systems. Adv. Colloid Interface Sci. 220, 54–77. https://doi.org/https://doi.org/10.1016/j.cis.2015.02.006

Mungan, N., 1969. Rheology and Adsorption of Aqueous Polymer Solutions. J. Can. Pet. Technol. 8, 45–50. https://doi.org/10.2118/69-02-01

Murty, B.S., Shankar, P., Raj, B., Rath, B.B., Murday, J., 2013. The Big World of Nanomaterials, in: Textbook of Nanoscience and Nanotechnology. Springer Berlin Heidelberg, Berlin, Heidelberg, pp. 1–28. https://doi.org/10.1007/978-3-642-28030-6_1

Nasrollahzadeh, M., Atarod, M., Sajjadi, M., Sajadi, S.M., Issaabadi, Z., 2019. Chapter 6 - Plant-Mediated Green Synthesis of Nanostructures: Mechanisms, Characterization, and Applications, in: Nasrollahzadeh, M., Sajadi, S.M., Sajjadi, M., Issaabadi, Z., Atarod, M. (Eds.), An Introduction to Green Nanotechnology, Interface Science and Technology. Elsevier, pp. 199–322. https://doi.org/https://doi.org/10.1016/B978-0-12-813586-0.00006-7

Nazari Moghaddam, R., Bahramian, A., Fakhroueian, Z., Karimi, A., Arya, S., 2015. Comparative Study of Using Nanoparticles for Enhanced Oil Recovery: Wettability Alteration of Carbonate Rocks. Energy & Fuels 29, 2111–2119. https://doi.org/10.1021/ef5024719

Needham, R.B., Doe, P.H., 1987. Polymer Flooding Review. J. Pet. Technol. 39, 1503–1507. https://doi.org/10.2118/17140-PA

Negin, C., Ali, S., Xie, Q., 2016. Application of nanotechnology for enhancing oil recovery – A review. Petroleum 2, 324–333. https://doi.org/10.1016/j.petlm.2016.10.002

Nwidee, L.N., Lebedev, M., Barifcani, A., Sarmadivaleh, M., Iglauer, S., 2017. Wettability alteration of oil-wet limestone using surfactant-nanoparticle formulation. J. Colloid Interface Sci. 504, 334–345. https://doi.org/https://doi.org/10.1016/j.jcis.2017.04.078

Ogiriki, S.O., Agunloye, M.A., Gbadamosi, A.O., Olafuyi, A.O., 2016. Exploitation of Bitumen from Nigerian Tar Sand Using Hot-Water/Steam Stimulation Process. Pet. Coal 58, 407–413. https://doi.org/10.1021/ac010415i

Olajire, A.A., 2014. Review of ASP EOR (alkaline surfactant polymer enhanced oil recovery) technology in the petroleum industry: Prospects and challenges. Energy 77, 963–982. https://doi.org/10.1016/j.energy.2014.09.005

Onyekonwu, M.O., Ogolo, N.A., 2010. Investigating the Use of Nanoparticles in Enhancing Oil Recovery, in: Nigeria Annual International Conference and Exhibition, 31 July - 7 August, Tinapa - Calabar, Nigeria Doi:10.2118/140744-MS. Society of Petroleum Engineers, pp. 1–14. https://doi.org/10.2118/140744-MS

Pal, S., Mushtaq, M., Banat, F., Al Sumaiti, A.M., 2018. Review of surfactant-assisted chemical enhanced oil recovery for carbonate reservoirs: challenges and future perspectives. Pet. Sci. 15, 77–102. https://doi.org/10.1007/s12182-017-0198-6

Paul, D.R., Robeson, L.M., 2008. Polymer nanotechnology: Nanocomposites. Polymer (Guildf). 49, 3187–3204. https://doi.org/10.1016/j.polymer.2008.04.017

Pitts, M.J., Campbell, T.A., Surkalo, H., Wyatt, K., 1995. Polymer Flood of the Rapdan Pool, Saskatchewan, Canada. Soc. Pet. Eng. 10, 183–186. https://doi.org/10.2118/27820-PA

Pitts, M.J., Dowling, P., Wyatt, K., Surkalo, H., Adams, K.C., 2006. Alkaline-Surfactant-Polymer Flood of the Tanner Field, in: SPE-100004-MS, Presented at SPE/DOE Symposium on Improved Oil Recovery, 22-26 April, Tulsa, Oklahoma, USA. Society of Petroleum Engineers, pp. 1–5. https://doi.org/10.2118/100004-MS

Pitts, M.J., Wyatt, K., Surkalo, H., 2004. Alkaline-Polymer Flooding of the David Pool, Lloydminster Alberta, in: SPE-89386-MS, Presented at SPE/DOE Symposium on Improved Oil Recovery, 17-21 April, Tulsa, Oklahoma. Society of Petroleum Engineers, pp. 1–6. https://doi.org/10.2118/89386-MS

Pogaku, R., Mohd Fuat, N.H., Sakar, S., Cha, Z.W., Musa, N., Awang Tajudin, D.N.A., Morris, L.O., 2017. Polymer flooding and its combinations with other chemical injection methods in enhanced oil recovery. Polym. Bull. 74, 1–22. https://doi.org/10.1007/s00289-017-2106-z

Ponnapati, R., Karazincir, O., Dao, E., Ng, R., Mohanty, K.K., Krishnamoorti, R., 2011. Polymer-Functionalized Nanoparticles for Improving Waterflood Sweep Efficiency: Characterization and Transport Properties. Ind. Eng. Chem. Res. 50, 13030–13036. https://doi.org/10.1021/ie2019257

Pope, G.A., 2011. Recent Developments and Remaining Challenges of Enhanced Oil Recovery. J. Pet. Sci. Eng. SPE-0711-0065-JPT 63, 65–68.

Pratap, M., Gauma, M.S., 2004. Field Implementation of Alkaline-Surfactant-Polymer (ASP) Flooding : A maiden effort in India, in: SPE-88455-MS, Presented at SPE Asia Pacific Oil and Gas Conference and Exhibition, 18-20 October, Perth, Australia. Society of Petroleum Engineers, pp. 1–5. https://doi.org/10.2118/88455-MS

Pu, H., Xu, Q., 2009. An Update and Perspective on Field-Scale Chemical Floods in Daqing Oilfield, China, in: SPE-118746-MS, Presented at SPE Middle East Oil and Gas Show and Conference, 15-18 March, Manama, Bahrain. Society of Petroleum Engineers, pp. 1–8. https://doi.org/10.2118/118746-MS

Pye, D.J., 1964. Improved Secondary Recovery by Control of Water Mobility. J. Pet. Technol. 16, 911–916. https://doi.org/10.2118/845-PA

Rafati, R., Haddad, A.S., Hamidi, H., 2016. Experimental study on stability and rheological properties of aqueous foam in the presence of reservoir natural solid particles. Colloids Surfaces A Physicochem. Eng. Asp. 509, 19–31. https://doi.org/https://doi.org/10.1016/j.colsurfa.2016.08.087

Raffa, P., Broekhuis, A.A., Picchioni, F., 2016. Polymeric surfactants for enhanced oil recovery: A review. J. Pet. Sci. Eng. 145, 723–733.

Ragab, A.M.S., 2014. Investigating the Potential of Nanomaterial for Enhanced Oil Recovery : State of Art. J. Sci. Technol. 6, 25–40.

Rahimi, K., Adibifard, M., 2015. Experimental Study of the Nanoparticles Effect on Surfactant Absorption and Oil Recovery in One of the Iranian Oil Reservoirs. Pet. Sci. Technol. 33, 79–85. https://doi.org/10.1080/10916466.2014.950382

Rashidi, M., Blokhus, A.M., Skauge, A., 2011. Viscosity and retention of sulfonated polyacrylamide polymers at high temperature. J. Appl. Polym. Sci. 119, 3623–3629. https://doi.org/10.1002/app.33056

Rezaei, A., Abdi-Khangah, M., Mohebbi, A., Tatar, A., Mohammadi, A.H., 2016. Using surface modified clay nanoparticles to improve rheological behavior of Hydrolized Polyacrylamid (HPAM) solution for enhanced oil recovery with polymer flooding. J. Mol. Liq. 222, 1148–1156. https://doi.org/10.1016/j.molliq.2016.08.004

Rezvani, H., Khalilnezhad, A., Ganji, P., Kazemzadeh, Y., 2018. How ZrO2 nano-particles improve the oil recovery by affecting the interfacial phenomena in the reservoir conditions? J. Mol. Liq. 252, 158–168. https://doi.org/https://doi.org/10.1016/j.molliq.2017.12.138

Romero-Zerón, L., 2012. Advances in Enhanced Oil Recovery Processes, in: Introduction to Enhanced Oil Recovery (EOR) Processes and Bioremediation of Oil Contaminated Sites. pp. 1–43. https://doi.org/10.5772/52807

Roustaei, A., Moghadasi, J., Bagherzadeh, H., Shahrabadi, A., 2012. An Experimental Investigation of Polysilicon Nanoparticles' Recovery Efficiencies through Changes in Interfacial Tension and Wettability Alteration, in: SPE-156976-MS, Presented at SPE International Oilfield Nanotechnology Conference and Exhibition, 12-14 June, Noordwijk, The Netherlands. Society of Petroleum Engineers, pp. 1–7. https://doi.org/10.2118/156976-MS

Ryles, R.G., 1983. Elevated Temperature Testing of Mobility Control Reagents, in: SPE-12008-MS, SPE Annual Technical Conference and Exhibition, 5-8 October, San Francisco, California. Society of Petroleum Engineers, pp. 1–10. https://doi.org/10.2118/12008-MS

Sabhapondit, A., Borthakur, A., Haque, I., 2003. Characterization of acrylamide polymers for enhanced oil recovery. J. Appl. Polym. Sci. 87, 1869–1878. https://doi.org/10.1002/app.11491

Saboorian-Jooybari, H., Dejam, M., Chen, Z., 2016. Heavy oil polymer flooding from laboratory core floods to pilot tests and field applications: Half-century studies. J. Pet. Sci. Eng. 142, 85–100. https://doi.org/10.1016/j.petrol.2016.01.023

Saha, R., Uppaluri, R.V.S., Tiwari, P., 2018. Silica Nanoparticle Assisted Polymer Flooding of Heavy Crude Oil: Emulsification, Rheology, and Wettability Alteration Characteristics. Ind. Eng. Chem. Res. 57, 6364–6376. https://doi.org/10.1021/acs.iecr.8b00540

Salem Ragab, A.M., Hannora, A.E., 2015. A Comparative Investigation of Nano Particle Effects for Improved Oil Recovery – Experimental Work, in: SPE-175395-MS, Presented at SPE Kuwait Oil and Gas Show and Conference, 11-14 October, Mishref, Kuwait. Society of Petroleum Engineers, pp. 1–16. https://doi.org/10.2118/175395-MS

Samanta, A., Bera, A., Ojha, K., Mandal, A., 2010. Effects of alkali, salts, and surfactant on rheological behavior of partially hydrolyzed polyacrylamide solutions. J. Chem. Eng. Data 55, 4315–4322. https://doi.org/10.1021/je100458a

Sandiford, B.B., 1964. Laboratory and Field Studies of Water Floods Using Polymer Solutions to Increase Oil Recoveries. J. Pet. Technol. 16, 917–922. https://doi.org/10.2118/844-PA

Sandvik, E.I., Maerker, J.M., 1977. Application of Xanthan Gum for Enhanced Oil Recovery, in: Extracellular Microbial Polysaccharides. pp. 242–264. https://doi.org/10.1021/bk-1977-0045.ch019

Sarsenbekuly, B., Kang, W., Fan, H., Yang, H., Dai, C., Zhao, B., Aidarova, S.B., 2017. Study of salt tolerance and temperature resistance of a hydrophobically modified polyacrylamide based novel functional polymer for EOR. Colloids Surfaces A Physicochem. Eng. Asp. 514, 91–97. https://doi.org/https://doi.org/10.1016/j.colsurfa.2016.10.051

ShamsiJazeyi, H., Miller, C.A., Wong, M.S., Tour, J.M., Verduzco, R., 2014. Polymer-coated nanoparticles for enhanced oil recovery. J. Appl. Polym. Sci. 131, 1–13. https://doi.org/10.1002/app.40576

Sharma, T., Iglauer, S., Sangwai, J.S., 2016. Silica Nanofluids in an Oilfield Polymer Polyacrylamide: Interfacial Properties, Wettability Alteration, and Applications for Chemical Enhanced Oil Recovery. Ind. Eng. Chem. Res. 55, 12387–12397. https://doi.org/10.1021/acs.iecr.6b03299

Sharma, T., S.Sangwai, J., 2017. Silica nanofluids in polyacrylamide with and without surfactant: Viscosity, surface tension, and interfacial tension with liquid paraffin. J. Pet. Sci. Eng. 152, 575–585. https://doi.org/10.1016/J.PETROL.2017.01.039

Sheng, J.J., 2013. Polymer Flooding—Fundamentals and Field Cases, in: Enhanced Oil Recovery Field Case Studies. Elsevier, pp. 63–82. https://doi.org/10.1016/B978-0-12-386545-8.00003-8

Sheng, J.J., 2011a. Chapter 5 – Polymer Flooding, in: Modern Chemical Enhanced Oil Recovery. pp. 101–206. https://doi.org/10.1016/B978-1-85617-745-0.00005-X

Sheng, J.J., 2011b. Chapter 6 – Polymer Viscoelastic Behavior and Its Effect on Field Facilities and Operations, in: Modern Chemical Enhanced Oil Recovery. pp. 207–238. https://doi.org/10.1016/B978-1-85617-745-0.00006-1

Sinha Ray, S., Okamoto, M., 2003. Polymer/layered silicate nanocomposites: a review from preparation to processing. Prog. Polym. Sci. 28, 1539–1641. https://doi.org/10.1016/j.progpolymsci.2003.08.002

Sochi, T., 2010. Non-Newtonian flow in porous media. Polymer (Guildf). 51, 5007–5023. https://doi.org/10.1016/j.polymer.2010.07.047

Sofla, S.J.D., James, L.A., Zhang, Y., 2019. Understanding the behavior of H+-protected silica nanoparticles at the oil-water interface for enhanced oil recovery (EOR) applications. J. Mol. Liq. 274, 98–114. https://doi.org/https://doi.org/10.1016/j.molliq.2018.09.049

Sorbie, K.S., 1991. Polymer-Improved Oil Recovery, Glasgow and London: Blackie and Son Ltd. https://doi.org/10.1007/978-94-011-3044-8

Suleimanov, B.A., Ismailov, F.S., Veliyev, E.F., 2011. Nanofluid for enhanced oil recovery. J. Pet. Sci. Eng. 78, 431–437. https://doi.org/https://doi.org/10.1016/j.petrol.2011.06.014

Sun, X., Zhang, Y., Chen, G., Gai, Z., 2017. Application of Nanoparticles in Enhanced Oil Recovery: A Critical Review of Recent Progress. Energies 10, 345. https://doi.org/10.3390/en10030345

Szabo, M.T., 1975. Some Aspects of Polymer Retention in Porous Media Using a C14 Tagged Polyacrylamide, in: Rembaum, A., Sélégny, E. (Eds.), Polyelectrolytes and Their Applications. Springer Netherlands, Dordrecht, pp. 287–337. https://doi.org/10.1007/978-94-010-1783-1_19

Tang, C.Y., Yang, Z., 2017. Chapter 8 - Transmission Electron Microscopy (TEM), in: Hilal, N., Ismail, A.F., Matsuura, T., Oatley-Radcliffe, D. (Eds.), Membrane Characterization. Elsevier, pp. 145–159. https://doi.org/https://doi.org/10.1016/B978-0-444-63776-5.00008-5

Tang, J.C., Lin, G.L., Yang, H.C., Jiang, G.J., Chen-Yang, Y.W., 2007. Polyimide-silica nanocomposites exhibiting low thermal expansion coefficient and water absorption from surface-modified silica. J. Appl. Polym. Sci. 104, 4096–4105. https://doi.org/10.1002/app.26041

Thomas, A., 2016. Polymer Flooding, in: Romero-Zeron, L. (Ed.), Chemical Enhanced Oil Recovery (CEOR) - A Practical Overview. InTech, Rijeka, pp. 25–50. https://doi.org/10.5772/64623

Thomas, S., 2007. Enhanced Oil Recovery - An Overview. Oil Gas Sci. Technol. - Rev. l'IFP 63, 9–19. https://doi.org/10.2516/ogst:2007060

Tian, J., Xu, J., Zhu, F., Lu, T., Su, C., Ouyang, G., 2013. Application of nanomaterials in sample preparation. J. Chromatogr. A 1300, 2–16. https://doi.org/10.1016/j.chroma.2013.04.010

Tiwari, D., Marathe, R.V., Patel, N.K., Ramachandran, K.P., Maurya, C.R., Tewari, P.K., 2008. Performance Of Polymer Flood In Sanand Field, India - A Case Study, in: SPE-114878-MS, Presented at SPE Asia Pacific Oil and Gas Conference and Exhibition, 20-22 October, Perth, Australia. Society of Petroleum Engineers, pp. 1–9. https://doi.org/10.2118/114878-MS

Torsater, O., Engeset, B., Hendraningrat, L., Suwarno, S., 2012. Improved Oil Recovery by Nanofluids Flooding: An Experimental Study, in: SPE-163335-MS, Presented at SPE Kuwait International Petroleum Conference and Exhibition, 10-12 December, Kuwait City, Kuwait. Society of Petroleum Engineers, pp. 1–9. https://doi.org/10.2118/163335-MS

Treiber, L.E., Owens, W.W., 1972. A Laboratory Evaluation of the Wettability of Fifty Oil-Producing Reservoirs. Soc. Pet. Eng. J. 12, 531–540. https://doi.org/10.2118/3526-PA

Urbissinova, T.S., Trivedi, J., Kuru, E., 2010. Effect of Elasticity During Visco-elastic Polymer Flooding: A Possible Mechanism of Increasing the Sweep Efficiency. SPE-133471-PA, J. Can. Pet. Technol. 49, 49–56.

Vargo, J., Turner, J., Bob, V., Pitts, M.J., Wyatt, K., Surkalo, H., Patterson, D., 2000. Alkaline-Surfactant-Polymer Flooding of the Cambridge Minnelusa Field. SPE-68285-PA, SPE Reserv. Eval. Eng. 3, 552–558. https://doi.org/10.2118/68285-PA

Veerabhadrappa, S.K., 2013. Study of Effects of Polymer Elasticity on Enhanced Oil Recovery by Core Flooding and Visualization Experiments. A thesis submitted to the department of civil and environmental engineering, University of Alberta

Veerabhadrappa, S.K., Doda, A., Trivedi, J.J., Kuru, E., 2013a. On the Effect of Polymer Elasticity on Secondary and Tertiary Oil Recovery. Ind. Eng. Chem. Res. 52, 18421–18428. https://doi.org/10.1021/ie4026456

Veerabhadrappa, S.K., Trivedi, J.J., Kuru, E., 2013b. Visual Confirmation of the Elasticity Dependence of Unstable Secondary Polymer Floods. Ind. Eng. Chem. Res. 52, 6234–6241. https://doi.org/10.1021/ie303241b

Wang, D., Cheng, J., Yang, Q., Wenchao, G., Qun, L., Chen, F., 2000. Viscous-Elastic Polymer Can Increase Microscale Displacement Efficiency in Cores, in: SPE-63227-MS Presented at SPE Annual Technical Conference and Exhibition, 1-4 October, Dallas, Texas. Society of Petroleum Engineers, pp. 1–10. https://doi.org/10.2118/63227-MS

Wang, D., Wang, G., Wu, W., Xia, H., Yin, H., 2007. The Influence of Viscoelasticity on Displacement Efficiency--From Micro to Macro Scale, in: SPE-109016-MS, Presented at SPE Annual Technical Conference and Exhibition, 11-14 November, Anaheim, California, U.S.A. Society of Petroleum Engineers, pp. 1–10. https://doi.org/10.2118/109016-MS

Wasan, D., Nikolov, A., Kondiparty, K., 2011. The wetting and spreading of nanofluids on solids: Role of the structural disjoining pressure. Curr. Opin. Colloid Interface Sci. 16, 344–349. https://doi.org/10.1016/j.cocis.2011.02.001

Wasan, D.T., Nikolov, A.D., 2003. Spreading of nanofluids on solids. Nature 423, 156–159.

Wassmuth, F.R., Green, K., Arnold, W., Cameron, N., 2009. Polymer Flood Application to Improve Heavy Oil Recovery at East Bodo. J. Can. Pet. Technol. 48, 55–61. https://doi.org/10.2118/09-02-55

Watson, A., Trahan, G.A., Sorensen, W., 2014. An Interim Case Study of an Alkaline-Surfactant-Polymer Flood in the Mooney Field, Alberta, Canada, in: SPE-169154-MS, Presented at SPE Improved Oil Recovery Symposium, 12-16 April, Tulsa, Oklahoma, USA. Society of Petroleum Engineers, pp. 1–16. https://doi.org/10.2118/169154-MS

Wegner, J., 2015. Investigation of polymer enhanced oil recovery (EOR) in microfluidic devices that resemble porous media - An experimental and numerical approach, Oil Gas European Magazine.

Wegner, J., Ganzer, L., 2013. Numerical Analysis of Polymer Micro-model Flooding Experiments, in: Hou, M.Z., Xie, H., Were, P. (Eds.), Clean Energy Systems in the Subsurface: Production, Storage and Conversion: Proceedings of the 3rd Sino-German Conference ``Underground Storage of CO2 and Energy'', Goslar, Germany, 21-23 May 2013. Springer Berlin Heidelberg, Berlin, Heidelberg, pp. 131–142. https://doi.org/10.1007/978-3-642-37849-2_11

Wei, B., 2016. Advances in Polymer Flooding. https://doi.org/10.5772/60142

Wei, B., Romero-Zerón, L., Rodrigue, D., 2014. Oil displacement mechanisms of viscoelastic polymers in enhanced oil recovery (EOR): a review. J. Pet. Explor. Prod. Technol. 4, 113–121. https://doi.org/10.1007/s13202-013-0087-5

Wei, Y., Babadagli, T., 2017. Alteration of Interfacial Properties by Chemicals and Nanomaterials To Improve Heavy Oil Recovery at Elevated Temperatures. Energy & Fuels 31, 11866–11883. https://doi.org/10.1021/acs.energyfuels.7b 02173

Willhite, G.P., Dominguez, J.G., 1977. Mechanisms of Polymer Retention in Porous Media, in: Improved Oil Recovery by Surfactant and Polymer Flooding. pp. 511–554. https://doi.org/10.1016/B978-0-12-641750-0.50021-9

Wiśniewska, M., 2012. The temperature effect on the adsorption mechanism of polyacrylamide on the silica surface and its stability. Appl. Surf. Sci. 258, 3094–3101. https://doi.org/https://doi.org/10.1016/j.apsusc.2011.11.044

Wiśniewska, M., Chibowski, S., Urban, T., 2016a. Influence of temperature on adsorption mechanism of anionic polyacrylamide in the Al2O3 –aqueous solution system. Fluid Phase Equilib. 408, 205–211.

Wiśniewska, M., Chibowski, S., Urban, T., Sternik, D., Terpiłowski, K., 2016b. Impact of anionic polyacrylamide on stability and surface properties of the Al2O3–polymer solution system at different temperatures. Colloid Polym. Sci. 294, 1511–1517. https://doi.org/10.1007/s00396-016-3906-7

Wu, Y., Chen, W., Dai, C., Huang, Y., Li, H., Zhao, M., He, L., Jiao, B., 2017. Reducing surfactant adsorption on rock by silica nanoparticles for enhanced oil recovery. J. Pet. Sci. Eng. 153, 283–287. https://doi.org/10.1016/j.petrol.2017.04.015

Wu, Y., Wang, K.-S., Hu, Z., Bai, B., Shuler, P.J., Tang, Y., 2009. A New Method for Fast Screening of Long Term Thermal Stability of Water-Soluble Polymers For Reservoir Conformance Control, in: SPE Annual Technical Conference and Exhibition, 4-7 October, New Orleans, Louisiana. Society of Petroleum Engineers, pp. 1–11. https://doi.org/10.2118/124257-MS

Xia, H., Wang, D., Wang, G., Ma, W., Deng, H.W., Liu, J., 2008. Mechanism of the Effect of Micro-Forces on Residual Oil in Chemical Flooding, in: SPE-114335-MS, Presented at SPE Symposium on Improved Oil Recovery, 20-23 April, Tulsa, Oklahoma, USA. Society of Petroleum Engineers, pp. 1–10.

Yekeen, N., Manan, M.A., Idris, A.K., Padmanabhan, E., Junin, R., Samin, A.M., Gbadamosi, A.O., Oguamah, I., 2018. A comprehensive review of experimental studies of nanoparticles-stabilized foam for enhanced oil recovery. J. Pet. Sci. Eng. 164, 43–74. https://doi.org/https://doi.org/10.1016/j.petrol.2018.01.035

Yousefvand, H., Jafari, A., 2015. Enhanced Oil Recovery Using Polymer/nanosilica. Procedia Mater. Sci. 11, 565–570. https://doi.org/10.1016/j.mspro.2015.11.068

Yousefvand, H.A., Jafari, A., 2018. Stability and flooding analysis of nanosilica/ NaCl /HPAM/SDS solution for enhanced heavy oil recovery. J. Pet. Sci. Eng. 162, 283–291. https://doi.org/https://doi.org/10.1016/j.petrol.2017.09.078

Zhang, J., Wang, K., He, F., Zhang, F., 1999. Ultimate Evaluation of the Alkali/Polymer Combination Flooding Pilot Test in XingLongTai Oil Field, in: SPE-57291-MS, Presented at SPE Asia Pacific Improved Oil Recovery Conference, 25-26 October, Kuala Lumpur, Malaysia. Society of Petroleum Engineers, pp. 1–10. https://doi.org/10.2118/57291-MS

Zhang, T., Davidson, D., Bryant, S.L., Huh, C., 2010. Nanoparticle-Stabilized Emulsions for Applications in Enhanced Oil Recovery, in: SPE-129885-MS, Presented at SPE Improved Oil Recovery Symposium, 24-28 April, Tulsa, Oklahoma, USA. Society of Petroleum Engineers, pp. 1–18. https://doi.org/10.2118/129885-MS

Zheng, C., Cheng, Y., Wei, Q., Li, X., Zhang, Z., 2017. Suspension of surface-modified nano-SiO 2 in partially hydrolyzed aqueous solution of polyacrylamide for enhanced oil recovery. Colloids Surfaces A Physicochem. Eng. Asp. 524, 169–177. https://doi.org/10.1016/j.colsurfa.2017.04.026

Zhijian, Q., Yigen, Z., Xiansong, Z., Jialin, D., 1998. A Successful ASP flooding Pilot in Gudong Oil Field, in: SPE-39613-MS, Presented SPE/DOE Improved Oil Recovery Symposium, 19-22 April, Tulsa, Oklahoma. Society of Petroleum Engineers, pp. 107–121. https://doi.org/10.2118/39613-MS