INVESTIGATION OF SILICA NANOPARTICLE-POLYMER HYBRID STABILITY UNDER HIGH TEMPERATURE AND SALINITY FOR OIL DISPLACEMENT APPLICATION

AMER ISKANDAR BIN RA'EIS

UNIVERSITI TEKNOLOGI MALAYSIA

INVESTIGATION OF SILICA NANOPARTICLE-POLYMER HYBRID STABILITY UNDER HIGH TEMPERATURE AND SALINITY FOR OIL DISPLACEMENT APPLICATION

AMER ISKANDAR BIN RA'EIS

A project report submitted in fulfilment of the
requirements for the award of the degree of
Master of Philosophy

Faculty of Chemical and Energy Engineering
Universiti Teknologi Malaysia

FEBRUARY 2023

DEDICATION

This thesis is dedicated to Allah s.w.t, my creator, tower of strength, and source of inspiration, wisdom, knowledge, and comprehension. He has been my source of strength throughout this program. This work is also dedicated to my parents, Ra'eis Aziz and Norliza Jamil, who have always loved me unconditionally and whose excellent example led me to work hard for my goals. To my buddy Faiz Rahim, Nurazam Talib and Zaki Hafizi, who are my source of inspiration and support during this Master programme. Sincere gratitude for your presence in my life. To my siblings Ammar and Aina, who have been influenced in every conceivable manner by our adventure. Thank you. My affection for you all is incalculable. God bless you.

ACKNOWLEDGEMENT

Spoke with several researchers, academics, and practitioners in writing my research. They have added to my comprehension and ideas. In particular, I would like to thank Dr. Abdul Rahim Risal, my principal thesis advisor, for his support, advice, criticisms, and friendship. Without his persistent attention and assistance, this thesis would not be offered in its current form. I am also grateful to Universiti Teknologi Malaysia (UTM) for allowing me to complete my education here. The librarians at UTM also deserve special recognition for the aid in delivering pertinent materials. My colleague graduate student also deserves credit for the assistance. My gratitude also goes to all of my colleagues and those who have assisted me on several occasions. The opinions and advice are undoubtedly valuable. Unfortunately, there is not enough room to mention all of them here.

ABSTRACT

Polymer flooding is one of the most often utilised enhanced oil recovery (EOR) techniques because it provides excellent recovery. Polymer flooding enhances sweep efficiency and reduce viscous fingering severity by increasing fluid and oil mobility. Due to excellent viscosifying nature, and well-known physiochemical properties, partially hydrolyzed polyacrylamide (HPAM) is the polymer most often utilised for the application. However, high temperatures restrict its application because polymer will acts as shear-thinning, such it undergoes shear degradation and reduces viscosity at high shear rates and quickly destabilized and therefore unable to achieve the expected effects. High salinity also causes the molecular chain of the polymer to collapse, which results in a much smaller molecule and hence, produces a lower viscosity solution. Adding nanoparticle to polymer solutions is now required to alter their properties. Therefore, this study aims to investigate the effect of silicon dioxide nanoparticles (SiO_2) addition to the stability of HPAM at high temperatures and salinity. The shear viscosity and the flooding performance at high temperature and high salinity gauge the stability of HPAM and the hybrid HPAM- SiO_2. A series of stability measurements as well as core flooding experiment with variations of conditions were conducted in order to know the improvement offered by this nanoparticle towards HPAM polymer. At a temperature of 110 ^{0}C, the addition of 1 wt% SiO_2 nanoparticle have enhanced the viscosity of 0.015 wt% HPAM, from 3.4 cP to 6.8 cP. This resulted in an almost 90% oil recovery rate. It also strengthened HPAM's salt tolerance at concentration of 5 wt% of NaCl by raising its viscosity up to 4.6 cP. This HPAM hybrid also have improve the oil recovery factor for this condition as well up to 85%. In conclusion, adding nanoparticles to HPAM will unquestionably increase the stability and potentially be used in EOR operations.

ABSTRAK

Banjir polimer adalah salah satu teknik pemulihan minyak yang dipertingkat dan ianya paling kerap digunakan kerana ia memberikan kadar pemulihan yang sangat baik. Banjir polimer dapat meningkatkan kecekapan sapuan dan mengurangkan keterukan penjarian likat dengan meningkatkan mobiliti cecair dan minyak. Disebabkan sifat kelikatan yang sangat baik, dan sifat fisiokimia yang terkenal, *partially hydrolyzed polyacrylamide* (HPAM) ialah polimer yang paling kerap digunakan untuk setiap aplikasi. Walau bagaimanapun, suhu tinggi menyekat penggunaannya kerana polimer akan menipis, sehingga ia mengalami degradasi dan mengurangkan kelikatan pada kadar ricih yang tinggi dan tidak akan stabil dengan cepat. Oleh itu, ianya tidak dapat mencapai kesan yang diharapkan. Kemasinan yang tinggi juga menyebabkan rantai molekul polimer akan runtuh, justeru menghasilkan molekul yang lebih kecil dan larutan kelikatan yang lebih rendah. Penambahan nanopartikel kepada larutan polimer kini diperlukan untuk mengubah sifatnya. Oleh itu, kajian ini bertujuan untuk menyiasat kesan penambahan nanozarah seperti silikon dioksida (SiO_2) terhadap kestabilan HPAM pada suhu dan kemasinan yang tinggi. Kelikatan dan prestasi banjir pada suhu tinggi dan kemasinan tinggi akan mempengaruhi kestabilan HPAM dan hibrid HPAM- SiO_2. Satu siri pengukuran kestabilan serta eksperimen banjir teras dengan variasi keadaan telah dijalankan untuk mengetahui peningkatan yang ditawarkan oleh nanopartikel ini terhadap polimer HPAM. Hasil menunjukkan bahawa, pada suhu 110 ^oC, penambahan 1 wt% SiO_2 nanopartikel telah meningkatkan kelikatan 0.015 wt% HPAM daripada 3.4 cP kepada 6.8 cP. Ianya juga menyebabkan kadar pemulihan minyak meningkat sehingga hampir 90%. Penambahan nanopartikel ini juga telah mengukuhkan toleransi HPAM terhadap kemasinan, yakni pada kepekatan 5 wt% NaCl dengan peningkatan kelikatan sehingga 4.6 cP, dan seterusnya pengabungan HPAM hibrid ini juga telah meningkatkan faktor pemulihan minyak untuk situasi ini sehingga hampir 85%. Kesimpulannya, penambahan nanopartikel pada HPAM sudah pasti akan meningkatkan kestabilan dan berpotensi digunakan dalam operasi EOR.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

EOR	–	Enhanced Oil Recovery
HPAM	–	Hydrolysed Polyacrylamide
WC	–	Water Cut
IPV	–	Inaccessive Pore Volume
WAG	–	Water Alternate Gas
OOIP	–	Original Oil In Place
IGIP	–	Initial Gas In Place
OGIP	–	Original Gas In Place
VAPEX	–	Vapour Extraction
SAGD	–	Steam Assisted Gravity Drainage
AS	–	Alkaline Surfactant
SP	–	Surfactant Polymer
AP	–	Alkaline Polymer
ASP	–	Alkaline Surfactant Polymer
C	–	Chromophore
CCP	–	Cationic-Conjugated Polymer
RF	–	Recovery Factor
EUR	–	Estimated Ultimate Recovery
TOC	–	Total Organic Content
NP	–	Nanoparticles

LIST OF SYMBOLS

F_R	-	resistance factor [f]
F_{RR}	-	residual resistance factor [f]
λ_w	-	brine mobility, [$\mu m^2/(mPa \cdot s)$]
λ_p	-	polymer solution mobility, [$\mu m^2/(mPa \cdot s)$]
k_w	-	effective permeability of brine, [um^2]
k_p	-	effective permeability of polymer solution [um^2]
u_w	-	viscosity of brine, [mPa.s]
u_p	-	viscosity of polymer solution, [mPa.s]
Q	-	flow rate through the core, [cm^3/s]
L	-	length of the core, [cm]
A	-	section area of the core, [cm^2]
Δp	-	pressure difference between two ends of the core, [atm]
k_{wi}	-	brine permeability before polymer flows through the core, [um^2]
k_{wa}	-	brine permeability after polymer flows through the core, [um^2]
k	-	pore permeability, [um^2]

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background of Research

There are three stages of oil recovery. The first stage will utilize the pressure within the reservoir to extract the oil. Inevitably, the reservoir's pressure will eventually decline, resulting in unsustainable oil production. Secondary stages include gas injection, water flooding and water injection, with the primary objective being of maintaining the reservoir pressure. Finally, tertiary or enhanced oil recovery (EOR) is always employed to improve the flooding process area and volumetric sweep efficiency. The three most commonly implemented EOR includes thermal EOR, chemical EOR, and gas miscible EOR. EOR overcomes well-known causes of inefficient flooding processes such as viscous fingering, bypassed oil, segregated flow, and altered reservoir wettability (Ali Mohsenatabar Firozjaiia and Hamid Reza Saghafi, 2020).

Chemically enhanced oil recovery improves volumetric sweep efficiency by lowering the water-oil mobility ratio such as polymer and decreases residual oil saturation by reducing the water-oil interfacial tension including surfactant or alkaline. Chemical flooding EOR comes in various forms, including alkaline flooding, surfactant flooding, surfactant-polymer flooding, polymer flooding, and alkaline-surfactant-polymer flooding. Theoretically, a water-soluble polymer raises the water viscosity and reduces the water-oil mobility ratio, improving the volumetric sweep's effectiveness (Ali Mohsenatabar Firozjaiia, 2020).

One of the most often used EOR methods is polymer flooding because it offers excellent recovery. Its objective is to improve sweep efficiency and lessen the severity of viscous fingering by decreasing the mobility ratio between the displacing fluid and the oil. The ability of the polymer to increase viscosity at a low concentration is the main emphasis of the design. The oil recovery improves as much as 15 to 20 percent for polymer compared to conventional water flooding. Polymer flooding works exceptionally in highly heterogeneous reservoirs where the viscous fingering is severe and in high-viscosity resident oil reservoirs where the mobility ratio is more than unity (Hamid Reza Saghafi, 2020).

Viscous fingering is the unstable displacement of viscous fluid by a less viscous fluid. Polymer flooding is frequently employed to combat viscous fingering. The fingering of injection fluid may harm the reservoir's flow, and the oil recovery of a reservoir. One reasons for viscous fingering is the reservoir rock's heterogeneous permeability. Water or another displacing fluid will only flow through the highly permeable layer, leaving the lower permeability layer's oil unaffected. Fluid viscosity, rock heterogeneity, temperature, and varying injection rates all contribute to viscous fingering. Gravity segregation, which separates the denser water from the oil, is a frequent term for this process. Combination of gravity segregation and viscous fingering results in the early water breakthrough and poor area and volumetric sweep efficiency result (Sameer Al-Hajria and Maziyar Sabet, 2019).

A detailed investigation of the polymer solution has been conducted to handle the significant flooding problem. A polymer solution pratically increase the water's viscosity, leading to a stronger viscous force and higher sweep efficiency. Large molecules known as polymers are made up of several monomers, or smaller chemical building blocks (Karl D, 2021). The two kinds of polymers are biopolymers and synthetic polymers. Synthetic polymers are huge molecular chains (macromolecules) and organic connections produced from natural products or by synthesising basic materials from oil, gas, or coal, such as hydrolysed polyacrylamide (HPAM). Biopolymers are organic polymers created by the cells of living things, such as chitosan. In biopolymers, monomeric units are covalently bonded to produce further enormous molecules. The three main categories of biopolymers are polynucleotides, polypeptides, and polysaccharides and these categories are based on the monomers used and the structure of the biopolymer produced (Md Irfan, and Christopher P. Lenn, 2021)

According to E. Mentzer, J. Heemskerk, and E.J.L. Koning (2017), the Marmul field in south Oman's sandstone reservoirs benefits from HPAM flooding, which lowers the total water-cut from 50% to 20%. Reducing water-cut extend the life of wells and save maintenance costs for surface infrastructure like separators. N. Sanmartim (2002) reported that the oil viscosity of 50 cP at 50°C after studying the polymer flooding process using HPAM at the Canto do Amaro oil field in Brazil. This outcome demonstrates the viability of polymer flooding in a reservoir containing high-viscosity oil. However, the use of polymer flooding is restricted by high salinity and high temperatures reservoirs, leading to several studies to enhance the HPAM's stability.

1.2 Problem Statement

Due to its cheap cost, tendency to viscosify, and well-known physiochemical features, partially hydrolysed polyacrylamide (HPAM) seems to be the most commonly used polymer in this situation. However, reservoir's high temperature and salinity restrict the use of HPAM. The chain's amide groups undergo substantial hydrolysis into a carboxylic acid in reservoir conditions. When these hydrolyzed products come in touch with the common cations found in reservoir brines, they precipitate. HPAM behaves as a shear-thinning polymer, reducing viscosity and going through shear degradation at high shear rates. This is because the polymer chains are severed at high shear rates (Song, 2006). Dandan Hu (2014) stated that mostly the limits for polymer flooding are that viscosity is lower than 100cP, the temperature is lower than 93 ^{0}C, water salinity is lower than 100,000 ppm, and formation permeability is higher than 20mD. In this high temperature and salinity environment, this polymer is quickly destabilized and unable to achieve the expected effects. High salinity also causes the polymer's molecular chain to collapse, producing a much smaller molecule and a lower viscosity solution.

Thermal and salinity degradation both impact the rheology behaviour of polymer solutions in porous media. The rate at which the polymer solution is hydrolyzed is directly influenced by temperature. Polymer flooding often resulted in HPAM hydrolyzing between 25 and 90 degrees. The most often utilised compounds in oilfield applications are partly hydrolyzed polyacrylamide (HPAM) and water-soluble polyacrylamide (PAM). HPAM polymers are often employed as mobility-controlling agents to raise the viscosity of stimulation fluids in polymer-augmented water flooding enhanced oil recovery (EOR) procedures to boost sweep efficiency. However, due to the thermal instability, applications of HPAM more than 90 °C and high salinity in between 100,000 and 200,000 ppm reservoir conditions are severely constrained. According to Algharaib M. (2014), this hydrolysis phenomenon may also decrease in the viscosity of a polymer solution. The viscosity of a polymer solution is influenced by several variables, including the concentration of the polymer, the rate at which it degrades, the temperature, as well as the salinity of the water used to prepare the solution.

The concentration of a dissolved polymer also affects the viscosity of the solution. The polymer segments tend to be surrounded with solvent molecules in appropriate solvents over other polymer segments. The polymer molecules, on the other hand, work to reduce the region of contact well with solvent molecules in poor solvents. Al-Zahrani (1990) explains that the extension of the polymer molecule, for instance, relies on the interaction of a polymer solvent, which has an immediate impact on its size as well as the viscosity of the solution.

Nowadays, adding nanoparticles into polymer solutions might be of interest, but more research on the viability of nanoparticles including the effects on oil recovery is still needed. The enhancement that SiO_2 offers to HPAM stability under high temperatures and high salinities, as well as the impact of these polymer hybrids on HPAM flooding performance, are nonetheless things that should be investigated.

1.3 Research objectives

The primary objective is to investigate the effect of silica nanoparticles addition on HPAM stability under high salinity and temperature.

1. To investigate the improvement silica dioxide nanoparticles (SiO_2) to the HPAM stability in high temperature and high salinity.
2. To investigate the effect of silica dioxide nanoparticles (SiO_2) on HPAM flooding performance under high temperature and high salinity.

1.4 Scope of Research

1.4.1 Nanoparticle Preparation

1. 100 ml of distilled water will be mixed with three different concentrations of HPAM such as 500,1000, and 1500 ppm.
2. Stir all the HPAM solution at 500 rpm for 2 hours using a magnetic stirrer for homogeneous solution.
3. Measure the shear viscosity of all HPAM solution using Brookfield Rheometer at a shear rate of $100s^{-1}$ for comparison matter.
4. The best viscosity result from the comparison will be selected, which justify as optimum performance for HPAM.
5. Prepare the selected HPAM concentration mixed with three different SiO_2 solutions such as 0.01, 0.1, and 1wt% by repeating all the previous preparation method.
6. The best viscosity result from the comparison will be selected, which justify as optimum performance for HPAM- SiO_2.

1.4.2 Temperature and Salinity Experiment for HPAM Solution

1. Heat the chosen HPAM solution at three different temperatures such as $50°C$, $70°C$, and $90°C$ for 24 hours and measure the shear viscosity using increasing shear rate from 100 to $1000s^{-1.}$ to determine the effect of temperature to the HPAM solution.
2. Prepare HPAM solution with additional of 20,000, 50,000, and 80,000 ppm of sodium chloride (NaCl) and measure the shear viscosity using

increasing shear rate from 100 to $1000s^{-1}$. to determine the effect of salinity to the HPAM solution stability.

3. All the process is repeated three times, and the average value is taken to ensure the consistent results.

1.4.3 Temperature and Salinity comparison between HPAM with HPAM-SiO_2 solution

1. Repeat all the experiments, which include temperature and salinity procedures with HPAM- SiO_2 solution
2. Compare the viscosity result on the worst temperature and salinity result made by HPAM solution previously for improvement matters.

1.4.4 Flooding performance Experiment

1. Prepare the several core samples using the glass beads as the core and the cylindrical column as a holder with 18 cm long and 3.8 cm inner diameter.
2. The porosity and permeability of each core were measured.
3. The core was saturated for 24 hours.
4. From the existing column made previously (sand + water), oil will be injected until it reaches the end of the column and some will come out with certain amount of water, then that amount of water will be recorded for finding irresidual water saturation, Swirr.

5. For finding the effective temperature, the test material (Water, HPAM, HPAM + SiO_2) will be heated up to the chosen temperature which is 110 degrees Celsius and it will be injected to the core model.
6. Same for effective salinity, test material (water, HPAM, HPAM + SiO_2) will be mixed with the highest chosen concentration which is 50,000 ppm of NaCl and it will be injected to the core model.
7. Data for Pressure change (ΔP) and Volume of oil out (Vo out) will be recorded in order to plot the graph of Resistance and Recovery Factor.

REFERENCES

Thomas S. Enhanced oil recovery: An overview. Oil & Gas Science and Technology-Revue de l'IFP, 2008. 63(1). 9-19

Levitt, D., Pope, G.A. Selection and screening of polymers for enhanced-oil recovery. In: Present. SPE Symp. Improv. Oil Recover. 20–23 April. Tulsa, Oklahoma, USA, Society of Petroleum Engineers, 2008. 2008. 1–18

Sun, X., Zhang, Y., Chen, G., Gai, Z. Application of nanoparticles in enhanced oil recovery: a critical review of recent progress. Energies 10, 2017. 345(1). 13-15

Samanta, A., Bera, A., Ojha, K., Mandal, A. Comparative studies on enhanced oil recovery by alkali–surfactant and polymer flooding. J. Pet. Explor. Prod. Technol, 2012. 2(1). 67–74

Kumar, N., Gaur, T., Mandal, A. Characterization of SPN pickering emulsions for application in enhanced oil recovery. J. Ind. Eng. Chem, 2017. 54(1). 304–315

Gowariker, V. R., Viswanathan, N. V. and Shreedhar, J. Polymer Science: New Age International, New Delhi, 2005. 2005. 7-13.

Chanda M. Introduction to Polymer Science and Chemistry, CRC Press, Taylor and Francis Group, FL, USA, 2006. 2006. 23 - 30

Cowie, J. M. G. Polymers: Chemistry and Physics of Modern Materials, Blackie Academic & Professional, Glasgow, 1991. 1991. 1-10

Pye, D.J. Improved secondary recovery by control of water mobility. J. Pet. Technol. 1964, 16(1), 911–916

Gogarty, W. Mobility control with polymer solutions. Soc. Pet. Eng. J. 1967, 7(1), 161–173.

Zhang, Y. Survey and Data Analysis of Polymer Flooding Pilot and Field Applications in China, 2015. 2015. 11-20

Al-Saadi, F.S, Al-amri, B.A, Al Nofli, S.M., Van Wunnik, J.N.M., Jaspers, H.F, Al Harthi, S, Shuaili, KSheng, J.J, Leonhardt, B, Azri, N. Status of polymer-flooding technology. J. Can. Pet. Technol, 2015. 54(1), 116–126

Sorbie, K. Polymer-Improved Oil Recovery Blackie & Son: Glasgow, Scotland, 1991. 1991. 126–163

Borthakur, A, Rahman, M.; Sarmah, A, Subrahmanyam, B. Partially Hydrolysed Polyacrylamide for Enhanced Oil-Recovery, 1995. 40(1), 90–94

Sun, Y, Saleh, L, Bai, B. Measurement and impact factors of polymer rheology in porous media, 2012. 2012. 187–188

Wever, D., Picchioni, F., Broekhuis, A. Polymers for enhanced oil recovery: A paradigm for structure–property relationship in aqueous solution. Prog. Polym. Sci., 2011, 36(1), 1558–1628.

G.A. Pope. Overview of chemical EOR, in: Casper EOR Workshop, Texas University, Austin, 2007. 2007. 55-60

K.S. Sorbie. Polymer-Improved Oil Recovery, CRC Press, Boca Raton, Florida, 1991. 1991. 22-31

C.G. Zheng, B.L. Gall, H.W. Gao, A.E. Miller, R.S. Bryant, SPE Reservoir Eng. Eval. Request for a scientific opinion on the appropriateness of existing methodologies to assess the potential risks associated with engineered and adventitious nanotechnologies, 2005. 2005. 11-12

McCarthy JF, McKay LD. Colloid transport in the subsurface: past, present, and future challenges, 2004. 3(1). 326–337

McCarthy JF, Zachara JM. Subsurface transport of contaminants. Environ Sci Technol, 1989. 23(1). 496–502

Wiggington NS, Huas KL, Hochella MF. Aquatic environmental nanoparticles. J Environ Monitor 9, 2007. 2007. 1306–1316

Ryan JN, Gschwend PM. Effect of solution chemistry on clay colloid release from an iron-oxide-coated aquifer sand. Environ Sci Technology, 1994. 28(1). 1717–1726

Esquivel EV, Murr LE A TEM. Analysis of nanoparticulates in a Polar ice core, 2004. 52(1).15–25

Paparazzo E. Evidence of Si-OH species on the surface of aged silica. J Vac Sci Technol, 1992. 10(1). 2892–2896

Md Irfan, Karl D. Stephen, Christopher P. Lenn. An experimental study to investigate novel physical mechanisms that enhance viscoelastic polymer flooding and further increase desaturation of residual oil saturation, 2021. 2021. 1-10

Saeed Akbaria, Syed Mohammad Mahmoodb, Negar Hadian Nasra, Sameer Al-Hajria, Maziyar Sabetc. A critical review of concept and methods related to accessible pore volume during polymer-enhanced oil recovery, 2019. 2019. 35-40

Ali Mohsenatabar Firozjaiia, Hamid Reza Saghafi. Review on chemical enhanced oil recovery using polymer flooding: Fundamentals, experimental and numerical simulation, 2020. 2020. 75-90

Koning, E.J.L., Mentzer, E and Heemskerk, J., Evaluation of a Pilot Polymer Flood in the Marmul Field, Oman, SPE 18092 presented at SPE Annual Technical Conference and Exhibition, 1988. 1988. 2-20

Abidin AZ, Puspasari T, Nugroho W. Polymers for enhanced oil recovery technology., 2012. 4(1). 11–16

Alvarado V, Manrique E. Enhanced oil recovery: an update review. Energies, 2010. 3(1). 1529–1575

Jiang Z, Zhu J. Cationic polyacrylamide: synthesis and application in sludge dewatering treatment: a review, 2014. 26(1). 629

Kamal MS, Sultan AS, Al-Mubaiyedh UA, Hussein IA. Review on polymer flooding: rheology, adsorption, stability, and field applications of various polymer systems. Polym Rev, 2015. 55(1). 491–530

Pope GA. The application of fractional flow theory to enhanced oil recovery. Soc Petrol Eng J, 1980. 20(1). 191–205

Quadri SMR, Jiran L, Shoaib M, Hashmet MR, AlSumaiti AM, Alhassan SM. Application of biopolymer to improve oil recovery in high temperature high salinity carbonate reservoirs. In: Abu Dhabi international petroleum exhibition and conference, 2015. 2015. 15-30

Sandrea I, Sandrea R. Global oil reserves recovery factors leave vast target for EOR technologies. Oil Gas,2007. 105(1). 44

Sarsenbekuly B, Kang W, Fan H, Yang H, Dai C, Zhao B et al. Study of salt tolerance and temperature resistance of a hydrophobically modified polyacrylamide based novel functional polymer for EOR, 2017. 514(1). 91–97

Wang W, Liu Y, Gu Y. Application of a novel polymer system in chemical enhanced oil recovery (EOR),2003. 281(1). 1046–1054

Wang Y, Lu ZY, Han YG, Feng YJ, Tang CL. A novel thermoviscosifying water-soluble polymer for enhancing oil recovery from high-temperature and high-salinity oil reservoirs, 2011. 306(1). 654–657

Wang G, Yi X, Feng X, Jing B, Ouyang J. Synthesis and study of a new copolymer for polymer flooding in high-temperature, high-salinity reservoirs. Chem Technol Fuels Oils, 2012. 48(1). 112–119

Zhu D, Wei L, Wang B, Feng Y Aqueous hybrids of silica nanoparticles and hydrophobically associating hydrolyzed polyacrylamide used for EOR in high-temperature and high-salinity reservoirs,2014. 7(1). 3858–3871

Aslam S, Vossoughi S, Willhite GP. Viscometric measurement of chromium (III): polyacrylamide gels by weissenberg rheogoniometer. 1984. 23(1). 533–562

Kharrat R, Vossoughi S. Rheological behavior of the gel systems used in enhanced oil recovery, 1992. 1(1). 478-480

Koohi AD, Seftie MV, Ghalam AZ, Moghadam AM, Sabet SZ. Rheological characteristics of sulphonated polyacrylamide/chromium triacetate hydrogels designed for water shut-off, 2010. 19(10). 757–770

Maghzi A, Mohebbi A, Kharrat R, Ghazanfari MH. An experimental investigation of silica nanoparticles effect on the rheological behavior of polyacrylamide solution to enhance heavy oil recovery, 2013. 31(5). 500–508

Modesto M, Juan CA, Julio EV. Successful field application of a high temperature conformance polymer in Mexico, 2009. 1(1). 1–13

Sheng JJ, Leonhardt B, Azri N. Status of polymer-flooding technology, 2015. 54(1). 116–126

Sohn WO, Maltin BK, Volz H. Preconditioning concepts in polymer flooding in high-salinity reservoirs: laboratory investigations and case histories, 1990. 5(1). 503–507

Song KW, Kim YS, Chan GS Rheology of concentrated xanthan gum solutions: steady shear flow behavior, 2006. 7(2).129–138

Taylor KC, Nasr-El-Din HA Water-soluble hydrophobically associating polymer for improved oil recovery: a literature review. 1998. 19(1). 265–280

Torrealba VA, Hoteit H. Improved polymer flooding injectivity and displacement by considering compositionally-tuned slugs, 2019. 178. 14–26

Urbissinova TS, Trivedi J, Kuru E. Effect of elasticity during viscoelastic polymer flooding: a possible mechanism of increasing the sweep efficiency, 2010. 49(1). 49–56