ENHANCED OIL RECOVERY BY SURFACTANT ALTERNATE CARBONATED WATER INJECTION

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DEDICATION

Specially dedicated to:

My family for their endless support and motivation

.

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ABSTRACT

Surfactant alternate carbonated water (SACW) injection is a novel mode for enhanced oil recovery (EOR), a method to produce residual oil. This process may overcome the shortcomings that seriously associate carbon dioxide (CO_2) injection such as high CO_2 mobility, viscous fingering and gravity override. Combinations of sodium dodecyl sulfate (SDS) surfactant and carbonated water (CW) system were not used for EOR yet. So, SDS and CW were selected for evaluating wettability, interfacial tension (IFT), and displacement stability. In addition, the oil recovery factor (RF) was evaluated at different reservoir conditions, carbonation levels and SACW injection cycles scenarios. The sessile drop method was used to measure the contact angle in presence of CW, SDS solution and a mixture of CW and SDS at different quartz sandstone reservoir conditions. A sandpack model was utilised for CW, SDS, water flood (WF) and CO_2 flood to measure the displacement instability number (I_{sc}). The obtained results revealed that combinations of SDS and CW system reduce the IFT and contact angle. The IFT values for SDS solution with and without carbonation were 0.2 and 2 mN/m, respectively. The respective contact angles for SDS solution with and without carbonation were 32° and 21.7° at 50°C and 1500 psi. The I_{sc} for CW and WF were 11.6 and 10, respectively, which are considered stable at 60°C and 2750 psi. On the other hand, SDS and CO_2 flood processes revealed unstable displacement. Moreover, low pH of CW system depicted a significant change in the SDS adsorption on the glass beads as compared to non-CW system. The 100% CO_2 content, reservoir temperature of 60°C and pressure of 2750 psi increased RF up to 83.05, 84.42 and 85.22%, respectively. The highest RF was 86.58% which procured from the largest SDS slug scenario. In conclusion, SACW may have a positive impact on the recoverable oil and it can display a technical knowledge to study other techniques for EOR.

ABSTRAK

Suntikan air berkarbonat bersilih ganti dengan surfaktan (SACW) ialah mod baharu untuk perolehan minyak tertingkat (EOR), kaedah untuk pengeluaran minyak baki. Proses ini mungkin boleh mengatasi kelemahan yang serius berkaitan suntikan gas karbon dioksida (CO_2), misalnya pergerakan CO_2 yang tinggi, jejarian likat dan songsangan graviti. Gabungan sistem surfaktan natrium dodesil sulfat (SDS) dan air berkarbonat (CW) belum pernah diguna kan dalam EOR. Oleh itu, SDS dan CW dipilih untuk menilai kebolehbasahan, tegangan antara muka (IFT), dan kestabilan anjakan. Di samping itu, faktor perolehan minyak (RF) dinilai pada keadaan reservoir berbeza, tahap pengkarbonatan dan senario kitaran suntikan SACW. Kaedah titis sesil telah digunakan untuk mengukur sudut sentuh dengan kehadiran CW, larutan SDS dan campuran CW dan SDS pada keadaan reservoir pasir kuarza yang berbeza. Model pek pasir digunakan bagi CW, SDS, banjiran air (WF) dan banjiran CO_2 untuk mengukur nombor ketidakstabilan anjakan (I_{sc}). Keputusan yang diperoleh menunjukkan bahawa gabungan sistem SDS dan CW boleh mengurangkan IFT dan sudut sentuh. Nilai-nilai IFT untuk larutan SDS dengan dan tanpa pengkarbonatan masing-masing ialah 0.2 mN/m dan 2 mN/m. Sudut-sudut sentuh bagi larutan SDS dengan dan tanpa pengkarbonatan masing-masing ialah 32° dan 21.7° pada 50°C dan 1500 psi. Nilai I_{sc} bagi CW dan WF masing-masing ialah 11.6 dan 10, yang didapati stabil pada 60°C dan 2750 psi. Walau bagaimanapun, proses banjiran SDS dan CO_2 menunjukkan anjakan yang tidak stabil. Selain itu, sistem CW dengan nilai pH yang rendah menunjukkan perubahan yang ketara terhadap penjerapan SDS pada manik kaca berbanding sistem tanpa CW. Sistem dengan 100% kandungan CO_2, suhu reservoir 60°C dan tekanan 2750 psi telah meningkatkan RF masing-masing kepada 83.05%, 84.42%, dan 85.22%. Nilai tertinggi RF ialah 86.58% yang diperoleh daripada senario slug terbesar SDS. Kesimpulannya, SACW mungkin boleh memberi kesan yang positif terhadap perolehan minyak dan ia boleh menunjukkan pengetahuan teknikal untuk mengkaji teknik lain dalam EOR

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LIST OF ABBREVIATIONS

C^*		Wettability number, dimensionless
D	-	Sand pack diameter, cm
V	-	Displacing of Darcy velocity, m/day
μ_2	-	Oil viscosity, cp
μ_w	-	Water viscosity, cp
α	-	Interfacial tension, mN/m
K	-	absolute permeability, md
1_{sc}	-	Instability number, dimensionless
P	-	Pressure, psi
R	-	0.08314467 bar l/mol K (universal gas constant)
T	-	Temperature, °C
ρ_o	-	Oil density ,gm/cc
ρ_w	-	Water density, gm/cc
GOR	-	Gas oil ratio, m^3/m^3
PV	-	Pore volume, %
t	-	Time, min
RF	-	Recovery factor, fraction
CWI	-	Carbonated water injection
Mx	-	CO_2 solubility, mole/Kg
M1	-	The molality of dissolved Sodium in brine water, mole/L
	-	The molality of dissolved Potassium in brine water, mole/L
	-	The molality of dissolved Calcium in brine water, mole/L
	-	The molality of dissolved Magnesium in brine water, mole/L
	-	The molality of dissolved Chloride in brine water, mole/L
	-	CO_2 mole fraction, fraction
	-	The fugacity coefficient
	-	Standard chemical potential

- Constant
- Constants
- water vapor pressure, psi
- Critical pressure of water, psi
- Critical temperature, °K or °C
- Critical pressure, psi
- Constants
- Initial concentrations, mg/L
- equilibrium concentration, mg/L
- surfactant solution volume, L
- weight of the glass beads (adsorbent), gm
- Adsorption, mg/g
- Porosity, %
- Length of the porous media, cm
- Change in pressure over the media, atm
- Cross-sectional area across which flow occurs, cm^2
- Flow rate through the porous medium, cc/s
- Flow rate through the porous medium, cc/s
- Permeability, md
- Viscosity, cp
- Contact angle, degree
- Differential oil production volume at ( ), cc
- Oil production volume at ( ), cc
- Oil volume at ( ), cc
- Differential time at ( ), min
- Time at ( )
- Time at ( ), min
- Oil flow rate at, cc/min

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CHAPTER 1

INTRODUCTION

1.1 Overview

Enhanced Oil recovery (EOR) may be generally a technical term for all processes that utilize to enhance oil production, it can be applied after the primary production operations (Kokal and Al-Kaabi, 2010; Khan and Islam, 2007). In the last decade, EOR was received more attention mainly as a result of increasing the price of crude oil as well as the high significant quantities of recoverable crude oil that present in the reservoirs (Ko *et al.* 2014). In other words, all of the oil reservoirs are discovered might be candidate for EOR implementations as a result of the reservoirs still contain huge amount of crude oil (Wall and Archer, 1986). The sequences of the oil production scenarios follow primary depletion, secondary recovery and finally tertiary recovery operations (Khan and Islam, 2007). Furthermore, there is about 20 to 50% of oil that can be recovered by primary and secondary methods (Park *et al.* 2015). These methods are utilized in sequence.

Consequently, the utilization of chemical materials such as surfactants and carbon dioxide (CO_2) gas can be used for EOR (Jangda *et al.* 2014). The surfactant significantly improves oil recovery. However, the adsorption of surfactant on the reservoir rock decreases the amount of surfactant in the aqueous phase. Similarly, CO_2 gas has a particular effectiveness in recovering oil as well (Jangda *et al.* 2014).

Chemical flooding is a common term for injection operations which utilize particular chemicals such as surfactants that dissolved in the injection water for a purpose of improving oil recovery. The tertiary recovery scheme of surfactant flood that has been highly pursued throughout the past decades because of its ability to effect on the oil-water-interfacial tension and wettability alteration of the reservoir rock from an oil-wet surface to water-wet surface to extract the oil that remains trapped in the formation (Hou *et al.* 2015; Alotaibi *et al.* 2011). The one of the essential parameters of the reservoir physical property is the wettability. This parameter may have an effect on the aqueous phase relative permeability, oil recovery, waterflooding characteristics and the residual oil allocation. Therefore, several operations need to be assessed in order to modify the reservoir rock wettability for EOR (Thomas, 2008; Morrow, 1990; Golabi *et al.* 2012; Hou *et al.* 2015). Therefore, the injection of surfactant solution into the reservoir can reduce the interfacial tension (IFT) between brine water and residual oil (Rosen, 2004) from the original value of 30mN/m to about 0.001mN/m which causes to decrease the capillary force (Hirasaki *et al.* 2011). This interfacial tension value might split up the oil into tiny droplets that can be displaced from the rock pores by water.

Carbonated water flooding is another emerging EOR technique that utilize limited amount of CO_2 dissolved in the injection water. CO_2 gas has been implementing in many depleting oil reservoirs across the world to improve oil recovery for more than 30 years (Kechut *et al.* 2010). There are two methods can be used for CO_2 injection (Kechut *et al.* 2011). Firstly, gas-based method, in which CO_2 may be continuously injected in one rich phase or water alternating gas (WAG) injection. This technique requires very large quantities of CO_2. Furthermore, the CO_2 supercritical condition is normally injected which is above the critical temperature and pressure of 31.1 °C and 1030 psi, respectively. The secondly method is called water-base method, the CO_2 gas may be dissolved in brine water injection firstly, thereafter, the solution is injected into the reservoir followed by water flooding process. This technique scheme is known as carbonated water injection (CWI) (Kechut *et al.* 2011). Currently, some active research pursues in this area with the rationale that CWI can reduce gravity segregation encountered in conventional WAG processes. In this technology, CO_2 is dissolved in water until the solubility limit is reached depending upon pressure, temperature, and injection water salinity, thereafter the obtained carbonated water is then injected into the reservoir as EOR mode. Solubility of CO_2 in water decreases with increasing temperatures, it increases with increasing pressures, and it decreases with increasing water salinities.

1.2 Problem Statement

Surfactant alternating carbonated water (SACW) is a novel mode which had never used for EOR yet. Some significant shortcomings may seriously associate with the tertiary process of CO_2 injection such as high CO_2 mobility, and viscous fingering (Bakhtiyarov *et al.* 2007; Jangda, 2014). In addition, gravity override issue, CO_2 can tend to move to the top of formation and override the displaced fluids as a result of density difference between CO_2 and other fluids. Therefore, this gravity effect is exploited by flooding from the top of the reservoir and displacing fluids down dip. These problems lead to earlier breakthrough and very poor macroscopic and microscopic sweep efficiencies. Thus, these phenomena might cause of the residual oil to be inaccessible to the injected CO_2 and it is trapped by water. The improvement of well injectivity can be developed by surfactant alternating gas injection (SAG) as a result of gas mobility reduction at the flood front (Farajzadeh *et al.* 2016). However, the mobility of gas is high at the displacement contact between fluids because the viscosity of gas is less than viscosity of surfactant solution slug. Consequently, the instability of free gas slug can occur at earlier life of the process which leads to viscous fingering becomes high at flood front, early breakthrough, low recovery factor and slug of gas may be dramatically collapsed due to high gas velocity (Jangda, 2014). So, this issue can be severed when the water and oil viscosity ratio is unacceptable.

In addition, natural reservoir pressure depletion of trapped fluids is another factor that influences the oil production rate due to hydrocarbons extraction continuously during primary recovery method (Meyer, 2007). The natural pressure of the reservoir may be declined to a particular value. Consequently, the remaining crude oil cannot be pushed by the slug towards production side anymore (Terry, 2001; Donaldson *et al.* 1989; Park *et al.* 2015). This issue needs to be assessed by usually secondary and tertiary recoveries method such as chemical flooding process (Thomas, 2008; Jamaloei, 2009).

Furthermore, the high IFT between immiscible fluids of water and oil into the reservoir is one of the most important factors that substantially cause trapped oil into the pours media. Consequently, the water and oil saturations and displacement process are drastically effected by IFT. On the other hand, SACW technique may overcome these issues and restrict the mobility of the displacing fluid.

There is a significant surfactant adsorption on the rock surface during surfactant solution flooding causes to strip surfactant from the aqueous phase which leads to decrease the performance of the system (Iglauer *et al.* 2010; Park *et al.* 2015; Thomas, 2008; Jamaloei, 2009). Thus, the surfactant content into the slug may be lessened (Ibrahim, 2006). So, this is considered significantly unfavorable phenomenon as well.

There are few published data evaluating the performance of CWI under various conditions and injection scenarios which are carried out under consistent experimental conditions. Moreover, the capacity of the CWI technique to permanently store the injected CO_2 is still a challenge and requires more detailed studies to investigate the effect of various conditions on the CO_2 storage capacity of CWI.

To the best of my knowledge, the combination of sodium dodecyl sulphate (SDS) surfactant solution and carbonated water was selected in this study work for EOR purpose. For the aim, this research firstly may depict the influence of SDS solution and carbonated water mixture on the IFT and wettability alteration. In addition, the SACW was experimentally applied for packed sandstone porous media in order to study the effectiveness of carbonation level, reservoir pressure and temperature on the recovery factor. The SACW were applied to investigate the effectiveness of slug sizes of SDS solution and carbonated water on the oil recovery factor. The impact of combination of SDS solution and carbonated water on the recovery factor has not been comprehensively investigated yet. No reported simulation work or experimental study has been published for this oil recovery technique yet. It may depict a positive impact for EOR. Furthermore, the reasonable CO_2 solubility range into the injection brine water needs to be achieved when CW utilizes for EOR. An experiment study of SACW process for a sandpack sample should thus be undertaken in order to indicate if the proposed EOR is technically feasible.

1.3 Objectives

Based on the above referred problem statements, consequently, the objectives of this research are as follows:

1. To determine the wettability behaviour, IFT reduction and instability displacement of surfactant and carbonated water system at reservoir conditions.
2. To evaluate the feasibility and oil recovery efficiency of SACW flooding in quartz sand porous media.
3. To determine the optimal oil production strategy using different SACW injection scenarios.

1.4 Scope of Research Study

To achieve the objectives, the scope of this study included the following:

1. Interfacial tension measurement was carried out in room condition since there is no suitable equipment that can be used to determine the IFT in reservoir conditions. A set of carbonated water was prepared in high pressure and temperature condition' and the pressure' were gradually decreased until room conditions. Therefore, the determination of IFT between oil and brine water was conducted with different surfactant concentrations and different salinity concentrations of 10,000, 20,000 and 30,000 ppm at ambient condition. In addition, the determination of IFT between oil and carbonated water was conducted with different surfactant concentrations and different salinity concentrations such as 10,000, 20,000 and 30,000 ppm at ambient condition.
2. Determination of surface tension of brine water was carried out with different surfactant concentrations and different salinity concentrations of 10,000, 20,000 and 30,000 ppm at ambient condition.

3. The investigation of fluid displacement instability index such as water flooding, surfactant flooding, carbonated water flooding and CO_2 gas flooding was conducted at reservoir conditions.
4. The sessile drop method was used for wettability measurements as follows:
    a) The contact angle between crude oil, carbonated water and quartz sandstone was investigated at several temperatures (40°C, 50°C and 60°C), but at constant salinity and pressure of 30,000 ppm and 2000 psi, respectively. In addition, contact angle was measured at saline water concentrations of 30,000 ppm and 10,000 ppm, while temperature and reservoir pressure were constant at 40°C and 2000 psi respectively.
    b) The contact angle between crude oil, carbonated water and quartz sandstone was measured at several concentrations (0.0%, 50% and 100%) of carbonation level, but at constant temperature, salinity, and reservoir pressure of 60°C, 30,000 ppm and 2000 psi, respectively.
    d) The contact angle between crude oil, carbonated water mixed with solution of SDS concentration of 0.01wt% and quartz sandstone was examined at temperature of 40°C, 50°C and 60°C, salinity of 30,000 ppm and reservoir pressure of 1500 psi. In addition, a new model was generated for this work.
5. The oil flow rate and oil recovery factor were investigated during SACW and the effectiveness of some important parameters on improvement oil recovery factor were studied as follows:
    a) CO2 concentration effect was run at 0.0, 50, 100%
    b) Reservoir pressure effect was run at 1500, 2100 and 2750 psi
    c) Reservoir temperature effect was run at 40°C, 50°C and 60°C
    d) Tertiary mode effect of SACW cycles:
        i. First experiment: (Three cycles, each cycle contains slug size ratio of 0.25PV CW and 0.75PV surfactant)
        ii. Second experiment: (Three cycles, each cycle contains slug size ratio of 0.50PV CW and 0.50PV surfactant)
        iii. Third experiment: (Three cycles, each cycle contains slug size ratio of 0.75PV CW and 0.25PV surfactant)

1.5 Significant of the Study

Since the SACW is a new technique and may viable option for EOR. Therefore, this proposed study intends to exhibit the ambiguity about dependence of oil recovery on SACW cycles particularly at different CO_2 ratios in water (GWR) and to assess the ability of the process to produce a tertiary oi1 recovery from a sandpack core sample. In addition, the purpose of flooding cycle schemes is to reduce CO_2 velocity into pore space which leads to improve areal and vertical sweep efficiency and may procure the greatest potential impact on recovery factor (Pritchard and Nieman, 1992). Consequently, this study shall depict to what extend the effective of this process for incremental oil recovery.

Moreover, carbonated water has additional values in addition improving residual oil recovery. An added positive merit on carbonated water is the process of storing CO_2 gas that contained in the carbonated water into rock formation. The process of sequestration of CO_2 into a mineral solid would be done simultaneously with the introduction of carbonated water. Thus, this becomes another option of carbon capture and storing which ideally improve both oil recovery and nature conservation. This significance of carbonated water injection will surely become a factor of attraction in application of carbonated water in maturing field.

In addition, the use of SACW injection for EOR purpose is a new task in petroleum engineering and it needed to be examined and validated prior to it implemented in a full field scale. SACW usage for EOR faces with a huge question that is how combination of carbonated water and surfactant solution has an advantage for EOR process. This depicts that CO_2 is trapped into the porous media which causes water/oil IFT reduction and oil mobilization at low saturation. So, the residual oil saturation is effectively reduced. Therefore, these phenomena may enhance surfactant flooding and reflect a positive impact on the surfactant solution performance instead of additional any other chemicals. Therefore, the SACW might be undertaken in order to diminish surfactant amount and to avoid utilizing chemical materials that associate surfactant flooding such as alkaline and polymer.

REFERENCES

Adkins, S., Liyanage, P. J., Arachchilage, P., Gayani, W. P., Mudiyanselage, T., Weerasooriya, U., and Pope, G. A. (2010). A New Process for Manufacturing and Stabilizing High-Performance EOR Surfactants at Low Cost for High-Temperature, High-Salinity Oil Reservoirs. In *SPE Improved Oil Recovery Symposium*. Society of Petroleum Engineers.

Ahmadi, M. A., and Shadizadeh, S. R. (2013). Implementation of a High-Performance Surfactant for Enhanced Oil Recovery from Carbonate Reservoirs. *Journal of Petroleum Science and Engineering*, *110*, 66-73.

Al-Mutairi, S.M., Abu-Khamsin, S.A., Enamul Hossain, M., A (2012). Novel Approach to Handle Continuous Wettability Alteration during Immiscible CO_2 Flooding Process, Paper SPE 160638 *Presented the Abu Dhabi International Petroleum Exhibition & Conference Held in Abu Dhabi*, UAE, 11–14

AL-Mutairi S., S. A., M. T., Okasha, Hossain M. (2014). An Experimental Investigation of Wettability Alteration during CO_2 Immiscible Flooding. King Fahd University of Petroleum & Minerals. *Journal of Petroleum Science and Engineering* 120 (2014) 73–77

Alotaibi, M. B., Nasralla, R. A., and Nasr-El-Din, H. A. (2011). Wettability Studies using Low-Salinity Water in Sandstone Reservoirs. *SPE Reservoir Evaluation & Engineering*, *14*(06), 713-725.

Alvarez, J. O., Neog, A., Jais, A., and Schechter, D. S. (2014). Impact of Surfactants for Wettability Alteration in Stimulation Fluids and the Potential for Surfactant EOR in Unconventional Liquid Reservoirs. In *SPE Unconventional Resources Conference*. Society of Petroleum Engineers.

Anderson, W. G. (1987). Wettability Literature Survey-Part 6: The Effects of Wettability on Waterflooding. *Journal of Petroleum Technology*, *39*(12), 1-605.

Anderson, W. G. (1986). Wettability Literature Survey-Part 1: Rock/Oil/Brine Interactions and the Effects of Core Handling on Wettability. *Journal of Petroleum Technology*, *38*(10), 1-125.

Appelo, C. A. J. (2015). Principles, Caveats and Improvements in Databases for Calculating Hydrogeochemical Reactions in Saline Waters from 0 to 200° C and 1 to 1000atm. *Applied Geochemistry*, *55*, 62-71.

Ayirala, S. and Yousef, A. (2014). Injection water chemistry requirement guidelines for IOR/EOR. *SPE Improved Oil Recovery Symposium*. SPE-169048-MS. Society of Petroleum Engineers.

Bahramian, A., and Danesh, A. (2007). Prediction of Solid–Water–Hydrocarbon Contact Angle. *Journal of Colloid and Interface Science*, *311*(2), 579-586.

Bai, J. M., Fan, W. Y., Nan, G. Z., Li, S. P., and Yu, B. S. (2010). Influence of Interaction between Heavy Oil Components and Petroleum Sulfonate on the Oil–Water Interfacial Tension. *Journal of Dispersion Science and Technology*, *31*(4), 551-556.

Bakhtiyarov, S. I., Shakhverdiev, A. K., Panakhov, G. M., and Abbasov, E. M. (2007). Effect of Surfactant on Volume and Pressure of Generated CO_2 Gas. In *Production and Operations Symposium*. Society of Petroleum Engineers.

Bando, S., Takemura, F., Nishio, M., Hihara, E., and Akai, M. (2004). Viscosity of Aqueous NaCl Solutions with Dissolved CO_2 at (30 to 60) ^oC and (10 to 20) MPa. *Journal of Chemical & Engineering Data,* 49(5), 1328-1332.

Baranenko, V. I., Fal'kovskii, L. N., Kirov, V. S., Kurnyk, L. N., Musienko, A. N., and Piontkovskii, A. I. (1990). Solubility of Oxygen and Carbon Dioxide in Water. *Atomic Energy*, *68*(4), 342-346.

Baviere, M., Ruaux, E., and Defives, D. (1993). Sulfonate Retention by Kaolinite at High pH-Effect of Inorganic Anions. *SPE Reservoir Engineering*, *8*(02), 123-127

Bera, A., Kumar, T., Ojha, K., and Mandal, A. (2013). Adsorption of Surfactants on Sand Surface in Enhanced Oil Recovery: Isotherms, Kinetics and Thermodynamic Studies. *Applied Surface Science*, *284*, 87-99

Blackwell, R. J., Rayne, J. R., and Terry, W. (1959). Factors Influencing the Efficiency of Miscible Displacement. *Trans*., AIME 216, 1-8

Buckley, J. S. (1998b). Wetting Alteration of Solid Surfaces by Crude Oils and Their Asphaltenes. *Revue de l'Institut Français du Pétrole*, *53*(3), 303-312.

Buckley, J. S., Liu, Y. and Monsterleet, S., (1998a). Mechanisms of Wetting Alteration by Crude Oils. *SPE Journal*, 54-61.

Calvo, A. L., Chertcoff, R. H., Cachile, M. A., Rosen, M., and Cena, N. H. (1994). The Effect of Wettability on Two-Phase Flow. In *SPE Latin America/Caribbean Petroleum Engineering Conference*. Society of Petroleum Engineers.

Carroll, J. J., Slupsky, J. D., and Mather, A. E. (1991). The Solubility of Carbon Dioxide in Water at Low Pressure. *Journal of Physical and Chemical Reference Data*, *20*(6), 1201-1209.

Christensen, R. J. (1961, January). Carbonated Waterflood Results--Texas and Oklahoma. In *Annual Meeting of Rocky Mountain Petroleum Engineers of AIME*. Society of Petroleum Engineers.

Chuoke, R. L., Van Meurs, P., and van der Poel, C. (1959). The Instability of Slow, Immiscible, Viscous Liquid-Liquid Displacements in Permeable Media. *SPE,* SPE 1141-G

Collins, R. E. (1976). Flow of Fluids through Porous Materials. *PennWell Publishing Co*., Tulsa 196

Coskuner, G., and Bentsen, G. G. (1987). A New Stability Theory for Designing Graded Viscosity Banks. *Journal of Canadian Petroleum Technology*, *26*(06).

Craig, F.F. Jr. (1971). The Reservoir Engineering Aspects of Waterfloodin. *Richardson,* Texas: Monograph Series, SPE. Vol. 3, 29-77

Crovetto, R. (1991). Evaluation of Solubility Data of the System CO_2-H2O from 273 K to the Critical Point of Water. *Journal of Physical and Chemical Reference Data*, *20*(3), 575-589.

Curbelo, F. D., Santanna, V. C., Neto, E. L. B., Dutra, T. V., Dantas, T. N. C., Neto, A. A. D., and Garnica, A. I. (2007). Adsorption of Nonionic Surfactants in Sandstones. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, *293*(1), 1-4

Donaldson, E.C. and Thomas R.D., (1971). Microscopic Observations of Oil Displacement in Water-Wet and Oil-Wet Systems. *Society of Petroleum Engineers of AIME.* SPE 3555.

Donaldson, E. C., Chilingarian, G. V., and Yen, T. F. (Eds.). (1989). Enhanced Oil Recovery, II: Processes and Operations. Elsevier.

Donaldson, E.C., Lorenz, P. B and Thomas, R. D., (1969). Wettability Determination and Its Effect on Recovery Efficiency. *Journal Society of Petroleum Engineer.* Vol. 9, No. 1, pp. 13-20.

Dong, Y., Dindoruk, B., Ishizawa, C., and Lewis, E. J. (2011a). An Experimental Investigation of Carbonated Water Flooding. In *SPE Annual Technical Conference and Exhibition*. Society of Petroleum Engineers.

Dong, Y., Ishizawa, C., Lewis, E., and Dindoruk, B. (2011b). Carbonated Water Flood: What We Observed in Sand Pack Experiments. *In International Symposium of the Society of Core Analysts, Austin, Texas*, USA

Doorwar, S., and Mohanty, K. K. (2016). Viscous-Fingering Function for Unstable Immiscible Flows. *SPE Journal*, *22*(01), 19-31.

Doscher, T. M., and El-Arabi, M. (1981). High Pressure Model Studies of Oil Recovery by Carbon Dioxide. *In SPE/DOE Enhanced Oil Recovery Symposium*. Society of Petroleum Engineers.

Duan, Z., and Li, D. (2008). Coupled Phase and Aqueous Species Equilibrium of the H_2O –CO_2–NaCl–$CaCO_3$ System from 0 to 250° C, 1 to 1000bar with NaCl Concentrations Up To Saturation of Halite. *Geochimica et Cosmochimica Acta*, *72*(20), 5128-5145.

Duan, Z., and Sun, R. (2003). An Improved Model Calculating CO_2 Solubility in Pure Water and Aqueous NaCl Solutions from 273 to 533 K and from 0 to 2000 Bar. *Chemical Geology*, *193*(3), 257-271.

Enick, R. M., and Klara, S. M. (1990). CO_2 Solubility in Water and Brine under Reservoir Conditions. *Chemical Engineering Communications*, 90(1), 23-33.

Farajzadeh, R., Eftekhari, A. A., Hajibeygi, H., Kahrobaei, S., van der Meer, J. M., Vincent-Bonnieu, S., and Rossen, W. R. (2016). Simulation of Instabilities and Fingering in Surfactant Alternating Gas (SAG) Foam Enhanced Oil Recovery. *Journal of Natural Gas Science and Engineering*, *34*, 1191-1204.

Farhadinia, M., Delshad, M., (2010). Modeling and Assessment of Wettability Alteration Processes in Fractured Carbonates using Dual Porosity and Discrete Fracture Approaches, Paper SPE 129749, *Presented at the 2010 SPE Improved Oil Recovery Symposium,* Tulsa, Oklahoma, USA, April 24–28.

Fjelde, I., and Asen, S. M. (2010, January). Wettability Alteration during Water Flooding and Carbon Dioxide Flooding of Reservoir Chalk Rocks. In *SPE EUROPEC/EAGE Annual Conference and Exhibition*. Society of Petroleum Engineers.

Gale, W. W., and Sandvik, E. I. (1973). Tertiary Surfactant Flooding: Petroleum Sulfonate Composition-Efficacy Studies. *Society of Petroleum Engineers Journal*, *13* (04), 191-199

Ghedan, S. G., Canbaz, C. H., Boyd, D. A., Mani, G. M., and Haggag, M. K. (2010, January). Wettability Profile of a Thick Carbonate Reservoir by the New Rise in Core Wettability Characterization Method. In *Abu Dhabi International Petroleum Exhibition and Conference*. Society of Petroleum Engineers.

Golabi, E., Seyedeyn Azad, F., Ayatollahi, S., Hosseini, N., and Akhlaghi, N. (2012, January). Experimental Study of Wettability Alteration of Limestone Rock from Oil Wet to Water Wet by Applying Various surfactants. In *SPE Heavy Oil Conference Canada*. Society of Petroleum Engineers.

Green, D. W., and Willhite, G. P. (1998). Enhanced Oil Recovery. Richardson, TX: Henry L. *Doherty Memorial Fund of AIME*, Society of Petroleum Engineers. Vol. 6, pp. 143-154

Habermann, B. (1960). The Efficiency of Miscible Displacement as a Function of Mobility Ratio. *Trans*., AIME 219, 264-272

Hamouda, A. A., and Karoussi, O. (2008). Effect of Temperature, Wettability and Relative Permeability on Oil Recovery from Oil-Wet Chalk. *Energies*, 1(1), 19-34

He, Y., Yazhgur, P., Salonen, A., and Langevin, D. (2015). Adsorption–Desorption Kinetics of Surfactants at Liquid Surfaces. *Advances in Colloid and Interface Science*, 222, 377-384.

Hirasaki, G., Miller, C. A. and Puerto, M. (2011). Recent Advances in Surfactant EOR. *SPE Journal,* 16**,** 889-907.

Hou, B. F., Wang, Y. F., and Huang, Y. (2015). Mechanistic Study of Wettability Alteration of Oil-Wet Sandstone Surface using Different Surfactants. *Applied Surface Science*, *330*, 56-64.

Hu, J., Duan, Z., Zhu, C., and Chou, I. M. (2007). PVTx Properties of the CO 2–H 2 O and CO 2–H 2 O–NaCl Systems Below 647 K: Assessment of Experimental Data and Thermodynamic Models. *Chemical Geology*, *238*(3), 249-267.

Huang, A. B., Chikhliwala, E. D., and Yortsos, Y. C. (1984). Linear Stability Analysis of Immiscible Displacement Including Continuously Changing Mobility and Capillary Effects: Part II-General Basic Flow Profiles. In *SPE Annual Technical Conference and Exhibition*. Society of Petroleum Engineers.

Ibrahim, Z. B., Manap, A. A. A., Hamid, P. A., Hon, V. Y., Lim, P. H., and Wyatt, K. (2006). Laboratory Aspect of Chemical EOR Processes Evaluation for Malaysian Oilfields. In *SPE Asia Pacific Oil & Gas Conference and Exhibition*. Society of Petroleum Engineers.

Iglauer, S., Wu, Y., Shuler, P., Tang, Y., and Goddard, W. A. (2010). New surfactant classes for enhanced oil recovery and their tertiary oil recovery potential. *Journal of Petroleum Science and Engineering*, 71(1), 23-29

Iglauer, S., Wu, Y., Shuler, P., Tang, Y., and Goddard III, W. A. (2010). Analysis of the Influence of Alkyl Polyglycoside Surfactant and Cosolvent Structure on Interfacial Tension in Aqueous Formulations versus n-Octane. *Tenside Surfactants Detergents*, *47*(2), 87-97

Jafvert, C. T., Westall, J. C., Grieder, E., and Schwarzenbach, R. P. (1990). Distribution of Hydrophobic Ionogenic Organic Compounds between Octanol and Water: Organic Acids. *Environmental Science & Technology*, *24*(12), 1795-1803.

Jamaloei, B. Y. (2009). Insight into the Chemistry of Surfactant-Based Enhanced Oil Recovery Processes. *Recent Patents on Chemical Engineering*, *2*(1), 1-10.

Jamaloei, B. Y., Kharrat, R., and Asghari, K. (2012). The Influence of Salinity on the Viscous Instability in Viscous-Modified Low-Interfacial Tension Flow during Surfactant–Polymer Flooding in Heavy Oil Reservoirs. *Fuel*, *97*, 174-185.

Jangda, Z. Z., Sultan, A. S., Gajbhiye, R. N., Abu-khamsin, S. A., and Arshad, A. (2014). Evaluation of Fluorosurfactant Performance with Super-Critical CO_2 Flooding for High Salinity Carbonate Reservoirs. In *SPE EOR Conference at Oil and Gas West Asia*. Society of Petroleum Engineers.

Jha, K. N. N. (1986). A Laboratory Study of Heavy Oil Recovery with Carbon Dioxide. *Journal of Canadian Petroleum Technology*, *25*(02).

Kalaei, Hosein, Green, Don, Willhite, Paul, (2012). A New Dynamic Wettability Alteration Model for Oil-Wet Cores During Surfactant Solution Imbibition,

Paper SPE 153329. *Presented at the 2012 SPE Improved Oil Recovery Symposium*, Tulsa, Oklahoma, USA, April 14–18.

Karagunduz, A., Pennell, K. D., and Young, M. H. (2001). Influence of a Nonionic Surfactant on the Water Retention Properties of Unsaturated Soils. *Soil Science Society of America Journal*, *65*(5), 1392-1399

Kechut, N. I., Riazi, M., Sohrabi, M., and Jamiolahmady, M. (2010). Tertiary Oil Recovery and CO_2 Sequestration by Carbonated Water Injection (CWI). In *SPE International Conference on CO_2 Capture, Storage, and Utilization*. Society of Petroleum Engineers. 10-12

Kechut, N. I., Sohrabi, M., and Jamiolahmady, M. (2011). Experimental and Numerical Evaluation of Carbonated Water Injection (CWI) for Improved oil recovery and CO_2 storage. In *SPE EUROPEC/EAGE Annual Conference and Exhibition*. Society of Petroleum Engineers. *Paper SPE,* 143005**,** 23-26.

Khan, M. I., and Islam, M. R. (2007). Handbook of Petroleum Engineering: Sustainable Operations. *Houston, TX: Gulf Publishing Company*, 461.

Ko, K. M., Chon, B. H., Jang, S. B., and Jang, H. Y. (2014). Surfactant Flooding Characteristics of Dodecyl Alkyl Sulfate for Enhanced Oil Recovery. *Journal of Industrial and Engineering Chemistry*, *20*(1), 228-233.

Kokal, S.,and Al-Kaabi, A. (2010). Enhanced Oil Recovery:Challenges& Opportunities. *World Petroleum Council: Official Publication*, *64*.

Koval, E. J. (1963). A Method for Predicting the Performance of Unstable Miscible Displacement in Heterogeneous Media. *Society of Petroleum Engineers Journal*, *3*(02), 145-154.

Li, D., and Duan, Z. (2007). The Speciation Equilibrium Coupling with Phase Equilibrium in the H2O– CO_2-NaCl System from 0 to 250 C, from 0 to 1000 Bar, and from 0 to 5 Molality of NaCl. *Chemical Geology*, *244*(3), 730-751. http://www.geochem-model.org/programs.htm

Li, D., Graupner, B. J., and Bauer, S. (2011). A Method for Calculating the Liquid Density for the CO_2–H2O–NaCl System Under CO_2 Storage Condition. *Energy Procedia*, *4*, 3817-3824.

Li, N. N., Thomas, R. K., and Rennie, A. R. (2016). Neutron Reflectometry of Anionic Surfactants on Sapphire: A Strong Maximum in the Adsorption Near the Critical Micelle Concentration. *Journal of Colloid and Interface Science*, *471*, 81-88

Li, X. P., Yu, L., Ji, Y. Q., Wu, B., Li, G. Z. , and Zheng, L. Q. (2009). New Type Flooding Systems in Enhanced Oil Recovery. *Chinese Chemical Letters,* 20, 1251-1254.

Li, Y., Zhang, W., Kong, B., Puerto**,** M., Bao, X., Sha, O., and Miller, C. (2016). Mixtures of Anionic/Cationic Surfactants: A New Approach for Enhanced Oil

Recovery in Low-Salinity, High-Temperature Sandstone Reservoir. *SPE Journal*, *21*(04), 1-164

Lin, E. C., and Huang, E. T. (1990). The Effect of Rock Wettability on Water Blocking during Miscible Displacement. *SPE Reservoir Engineering*, *5*(02), 205-212.

Liu, L., and Buckley, J. S. (1999). Alteration of Wetting of Mica Surfaces. *Journal of Petroleum Science and Engineering*, *24*(2), 75-83.

Lu, J., Liyanage, P. J., Solairaj, S., Adkins, S., Arachchilage, G. P., Kim, D. H., Britton, C., Weerasooriya, U., and Pope, G. A. (2014). New Surfactant Developments for Chemical Enhanced Oil Recovery. *Journal of Petroleum Science and Engineering,* 120, 94-101.

Liu, S., Zhang, D., Yan, W., Puerto, M., Hirasaki, G. J., and Miller, C. A. (2008). Favorable Attributes of Alkaline-Surfactant-Polymer Flooding. *SPE Journal*, *13*(01), 5-16

Mackay, D., Chau, A., Hossain, K., and Bobra, M. (1984). Measurement and prediction of the effectiveness of oil spill chemical dispersants. In *Oil Spill Chemical Dispersants: Research, Experience, and Recommendations*. ASTM STP840 International, P 48-52

Maini, B. B., Ionescu, E., and Batycky, J. P. (1986). Miscible Displacement of Residual Oil-Effect of Wettability on Dispersion in Porous Media. *Journal of Canadian Petroleum Technology*, *25*(03).

Mannhardt, K., and Novosad, J. J. (1991). Chromatographic Movement of Surfactant Mixtures in Porous Media. *Chemical Engineering Science*, *46*(1), 75-83

Mannhardt, K., Schramm, L. L., & Novosad, J. J. (1993). Effect of rock type and brine composition on adsorption of two foam-forming surfactants. *SPE Advanced Technology Series*, *1*(01), 212-218.

Mao, S., Zhang, D., Li, Y., and Liu, N. (2013). An Improved Model for Calculating CO_2 Solubility in Aqueous NaCl Solutions and the Application to CO_2 – H_2O–NaCl Fluid Inclusions. *Chemical Geology*, *347*, 43-58.

McRee, B.C. (1977). CO_2: How It Works, Where It Works. *Petroleum Engineer International*. November 1977, 49, No. 12, 52.

Meyer, J. P. (2007). Summary of Carbon Dioxide Enhanced Oil Recovery (CO_2 EOR) Injection Well Technology. *American Petroleum Institute*, *54*, p 8

Mohamed, I., He, J., and Nasr-El-Din, H. A. (2013). Effect of Brine Composition on CO_2/Limestone Rock Interactions during CO_2 Sequestration. *Journal of Petroleum Science Research*, (2), 14-26

Morrow, N. R.(1991). Introduction to Surface Phenomena in Oil Recovery *Surfactant Science Series. Interfacial Phenomena in Petroleum Recovery,* 36, 1-21

Morrow, N. R. (1990). Wettability and Its Effect on Oil Recovery. *Journal of Petroleum Technology*, *42*(12), 1-476.

Mosavat, N., and Torabi, F. (2014). Experimental Evaluation of the Performance of Carbonated Water Injection (CWI) under Various Operating Conditions in Light Oil Systems. *Fuel*, 123, 274-284

Muherei, M. A. M. (2009). *Adsorption of Surfactants to Shale and Sandstone and its Effect on Oily Drill Cuttings Decontamination* (Doctoral dissertation, Universiti Teknologi Malaysia). Faculty of Chemical and Natural Resources Engineering.

Mungan, N. (1966). Certain Wettability Effect in Laboratory Waterfloods. *SPE Annual Fall Meeting.* 3-6 Oct. Denver, USA. SPE 1203.

Nader Mosavat and Farshid Torabi (2014). *Experimental Evaluation of the Performance of Carbonated Water Injection (CWI) under Various Operating Conditions in Light Oil Systems.* Fuel, journal homepage: www.elsevier.com/locate/fuel

Nasralla, R. A., Bataweel, M. A., and Nasr-El-Din, H. A. (2013). Investigation of Wettability Alteration and Oil-Recovery Improvement by Low-Salinity Water in Sandstone Rock. *Journal of Canadian Petroleum Technology*, *52*(02), 144-154.

Owens, W.W. and Archer, D.L (1971). The Effect of Rock Wettability on Oil-Water Relative Permeability Relationships. *Journal of Petroleum Technology*. SPE 3034, 873-878

Park, S., Lee, E. S., and Sulaiman, W. R. W. (2015). Adsorption Behaviors of Surfactants for Chemical Flooding in Enhanced Oil Recovery. *Journal of Industrial and Engineering Chemistry*, *21*, 1239-1245.

Peredo-Mancilla, D., and Dominguez, H. (2016). Adsorption of Phenol Molecules by Sodium Dodecyl Sulfate (SDS) Surfactants Deposited on Solid Surfaces: A

Computer Simulation Study. *Journal of Molecular Graphics and Modelling*, *65*, 108-112

Perez, J. M., Poston, S. W., and Sharif, Q. J. (1992). Carbonated Water Imbibition Flooding: An Enhanced Oil Recovery Process for Fractured Reservoirs. In *SPE/DOE Enhanced Oil Recovery Symposium*. Society of Petroleum Engineers.

Peters, E. J. and D. L. Flock (1981). The Onset of Instability During Two-Phase Immiscible Displacement in Porous Media. *SPE Journal*, pp 249

Peters, E. J., and Khataniar, S. (1987). The Effect of Instability on Relative Permeability Curves obtained by the Dynamic-Displacement Method. *SPE Formation Evaluation*, *2*(04), 469-474.

Pi, Y. L., Peng, B., Zhao, Y. H., Lin, M. Q., and Li, M. Y. (2009). Investigation on the pH Variation Characteristics of CO_2-Brine System in High Pressure. *Applied Chemical Industry*, 38, 469-473

Pistone, S., Stacey, R., and Horne, R. (2011). The Significance of CO_2 Solubility In Geothermal Reservoirs. *Proceedings Thirty-Sixth Workshop on Geothermal Reservoir Engineering*. January 31 - February 2. Stanford, California: SGP-TR-191.

Potter, G. F. (1987). The Effects of CO_2 Flooding on Wettability of West Texas Dolomitic Formations. Paper SPE 16716. In *SPE Annual Technical Conference and Exhibition*. Society of Petroleum Engineers.

Qi, Z. Y., Wang, Y. F., Yu, H. Y., and Xu, X. L. (2014). Study on Wettability Alteration of Quartz Surface by Surfactants. *In Advanced Materials Research,* Vol. 962, pp. 539-543

Rao, D. N., Girard, M., and Sayegh, S. G. (1992b). The Influence of Reservoir Wettability on Waterflood and Miscible Flood Performance. *Journal of Canadian Petroleum Technology*, *31*(06).

Rao, N. D., Girard, M., Sayegh, S. G. (1992a). Impact of Miscible Flooding on Wettability, Relative Permeability, and Oil Recovery. *SPE Res. Eng.,* 7(02), 204–212, SPE 20522-PA.

Rosen, M. J. (2004). Emulsification by Surfactants. *Surfactants and Interfacial Phenomena, Third Edition*, 303-331.

Rosenqvist, J., Kilpatrick, A. and Yardley, B.W.D. (2012). Solubility of Carbon Dioxide in Aqueous Fluids and Mineral Suspensions at 294 K and Subcritical Pressures. *Applied Geochemistry*. 27, 1610-1614.

Salehi, M., Johnson, S. J., and Liang, J. T. (2008). Mechanistic Study of Wettability Alteration using Surfactants with Applications in Naturally Fractured Reservoirs. *Langmuir*, *24* (24), 14099-14107

Salehi, M. M., Safarzadeh, M. A., Sahraei, E., and Nejad, S. A. T. (2014). Comparison of Oil Removal in Surfactant Alternating Gas with Water Alternating Gas, Water Flooding and Gas Flooding in Secondary Oil Recovery Process. *Journal of Petroleum Science and Engineering*, *120*, 86-93

Schramm, L. L., Mannhardt, K., and Novosad, J. J. (1991). Electrokinetic Properties of Reservoir Rock Particles. *Colloids and Surfaces*, *55*, 309-331

Sohrabi, M., Riazi, M., Jamiolahmady, M., Kechut, N. I., Ireland, S., and Robertson, G. (2011). Carbonated Water Injection (CWI)–A Productive Way of Using CO_2 for Oil Recovery and CO_2 Storage. *Energy Procedia*, 4, 2192-2199

Somasundaran, P., and Hanna, H. S. (1985). Adsorption/Desorption of Sulfonate by Reservoir Rock Minerals in Solutions of Varying Sulfonate Concentrations. *Society of Petroleum Engineers Journal*, *25*(03), 343-350

Somasundaran, P., and Zhang, L. (2006). Adsorption of Surfactants on Minerals for Wettability Control in Improved Oil Recovery Processes. *Journal of Petroleum Science and Engineering*, *52*(1), 198-212

Tadesse Weldu Teklu, Waleed Alameri, Ramona M. Graves, and Hossein Kazemi and Ali M. AlSumaiti (2014). Low-salinity Water-alternating- CO_2 Flooding Enhanced Oil Recovery: Theory and Experiments. SPE-171767-MS. Presented at the Abu Dhabi International Petroleum Exhibition and Conference held in Abu Dhabi, UAE, 10–13 November 2014.

Tehrani, D., Danesh, A., Sohrabi, M., Henderson, G., (2001). Improved Oil Recovery from Oil-Wet and Mixed-Wet Reservoirs by Gas Flooding,

Alternately with Water. *Presented to IEA Annual Workshop & Symposium*, Vienna, September

Terry, R. E. (2001). Enhanced Oil Recovery. *Encyclopedia of Physical Science and Technology*, *18*, 503-518.

Thomas, S. (2008). Enhanced Oil Recovery-An Overview. *Oil & Gas Science and Technology-Revue de l'IFP*, *63*(1), 9-19.

Tiffin, D. L., and Yellig, W. F. (1983). Effects of Mobile Water on Multiple-Contact Miscible Gas Displacements. *Society of Petroleum Engineers Journal*, *23*(03), 447-455.

Treiber, L. E., and Owens, W. W. (1972). A Laboratory Evaluation of the Wettability of Fifty Oil-Producing Reservoirs. *Society of Petroleum Engineers Journal*, *12*(06), 531-540.

van Dijke, M.I.J., Sorbie, K.S., (2002). Pore-scale Network Model for Three-Phase Flow in Mixed-Wet Porous Media. *Phys. Rev*. E 66 (4), 046302.

Van Meurs, P., and Van der Poel, C. (1958). A Theoretical Description of Water-Drive Processes Involving Viscous Fingering. *Trans*., AIME 213, 103-12

Wall, C. G. and Archer, J. (1986). Petroleum Engineering Principles and Practice. *Graham & Trotman Ltd*

Wang, W., and Gupta, A. (1995). Investigation of the Effect of Temperature and Pressure on Wettability using Modified Pendant Drop Method. In *SPE Annual Technical Conference and Exhibition*. Society of Petroleum Engineers.

Wang, Z., Xu, S., and Acosta, E. (2015). Heat of Adsorption of Surfactants and Its Role on Nanoparticle Stabilization. *The Journal of Chemical Thermodynamics*, *91*, 256-266

Wiśniewska, M., Chibowski, S., and Urban, T. (2016). Adsorption Properties of the Nanozirconia/Anionic Polyacrylamide System-Effects of Surfactant Presence, Solution pH and Polymer Carboxyl Groups Content. *Applied Surface Science*, *370*, 351-356

Xie, X., and Morrow, N. R. (1999). Contact Angles on Quartz Induced by Adsorption Of Heteropolar Hydrocarbons. *Journal Of Adhesion Science And Technology*, *13*(10), 1119-1135.

Xie, X., Morrow, N. R., and Buckley, J. S. (2002). Contact Angle Hysteresis and the Stability of Wetting Changes Induced by Adsorption from Crude Oil. *Journal of Petroleum Science and Engineering*, *33*(1), 147-159.

Xing, W., Song, Y., Zhang, Y., Nishio, M., Zhan, Y., Jian, W. and Shen, Y. (2013). Research Progress of the Interfacial Tension in Supercritical CO 2-Water/Oil System. *Energy Procedia,* 37**,** 6928-6935.

Xu, Q., Vasudevan, T. V., and Somasundaran, P. (1991). Adsorption of Anionic—Nonionic and Cationic—Nonionic Surfactant Mixtures on Kaolinite. *Journal of Colloid and Interface Science*, *142*(2), 528-534

Xu, W., Ayirala, S. C., and Rao, D. N. (2006). Compositional Dependence of Wetting and Contact Angles in Solid-Liquid-Liquid Systems under Realistic Environments. *The Canadian Journal of Chemical Engineering*, *84*(1), 44-51.

Yang, S. Y., Hirasaki, G. J., Basu, S., and Vaidya, R. (1999). Mechanisms for Contact Angle Hysteresis and Advancing Contact Angles. *Journal of Petroleum Science and Engineering*, *24*(2), 63-73.

Yih-Bor Chang, B.K. Coats, and J.S. Nolen (1998). *A Compositional Model for CO_2 Floods Including CO_2 Solubility in Water.* SPE Reservoir Evaluation & Engineering, April 1998

You, Q., Wang, C., Ding, Q., Zhao, G., Fang, J., Liu, Y., and Geng, M. (2015). Impact of Surfactant in Fracturing Fluid on the Adsorption–Desorption Processes of Coalbed Methane. *Journal of Natural Gas Science and Engineering*, *26*, 35-41

Yuanhui, J. I., Xiaoyan, J. I., Xin, F. E. N. G., Chang, L. I. U., Linghong, L. Ü., and Xiaohua, L. U. (2007). Progress in the Study on the Phase Equilibria of the CO 2-H 2 O and CO 2-H 2 O-NaCl Systems. *Chinese Journal of Chemical Engineering*, *15*(3), 439-448.

Zeinali Hasanvand, M., Ahmadi, M. A., Shadizadeh, S. R., Behbahani, R., and Feyzi, F. (2013). Geological Storage of Carbon Dioxide by Injection of Carbonated Water in an Iranian Oil Reservoir: A Case Study. *Journal of Petroleum Science and Engineering*, 111, 170-177

Zekri, A. Y., Shedid, S. A., and Almehaideb, R. A. (2007). Possible Alteration of Tight Limestone Rocks Properties and the Effect of Water Shielding on the Performance of Supercritical CO_2 Flooding for Carbonate Formation. In *SPE Middle East Oil and Gas Show and Conference* (pp. 11-14).

Zheng, H., Feng, X. T., and Pan, P. Z. (2015). Experimental Investigation of Sandstone Properties under CO_2–NaCl Solution-Rock Interactions. *International Journal of Greenhouse Gas Control*, *37*, 451-470.

Zhenhao Duan, Rui Sun, Chen Zhu and I-Ming Chou (2006). An Improved Model for the Calculation of CO_2 Solubility in Aqueous Solutions Containing Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, and $SO4^{2-}$. *Marine Chemistry,* 98 (2006) 131–139