

Effects of Low Salinity Water Ion Composition on Wettability Alteration in Sandstone Reservoir Rock: A Laboratory Investigation

Abdolmohsen Shabib-Asl* Mohammed Abdalla Ayoub Mohammed Massoud Kermanioryani
Pedro Paulo Jose Valentim
Department of Petroleum Engineering, Faculty of Geoscience and Petroleum Engineering, Universiti Teknologi PETRONAS (UTP), Bandar Seri Iskandar, 31750, Tronoh, Perak, MALAYSIA.
*Email address of corresponding author: msn.shabib@gmail.com

Abstract

For various decades, water-flooding mechanisms have been playing important role for improving oil recovery. It was not until recently that researchers discovered that the ionic strength of the brine was substantial. With regard to this, many studies started being published which focused more on the comparison of effects of having high ionic strength and low ionic strength for brine during flooding processes. Low salinity water comprises brine concentration below 5000ppm. At optimum concentration, low salinity water (LSW) when injected into the reservoir enhances the oil recovery considerably. This is attributed to the change of reservoir rock wettability. The process governing these changes are not well understood thus requiring a scrupulous investigation. Moreover there is no a certain fixed salinity range. This study investigates wettability alteration of Berea sandstone rock with brine of different ion composition (NaCl, KCl, $MgCl_2$, $CaCl_2$, and formation water-mostly Mg^{2+} and Ca^{2+} ions) and strength (500ppm-6500ppm with exception of formation water which consisted of 13000ppm). For the study, (31) core slabs were extracted from the core plug then saturated with formation water (FW). Next, the slabs underwent aging process in crude oil at ambient pressure and a temperature of 80^0c. Later, the slabs were removed and immersed in containers with low salinity water at different ionic composition and strength, which is mentioned. The wettability was measured by applying the sessile drop method in certain range of time. According to the results, there have been significantly great change of wettability at Low salinity water in case of KCl was observed.

Keywords: ionic strength, wettability, low salinity water, saturation, brine composition

1. Introduction

In the last two decades, the level of investigation into low salinity water flooding has sharply increased. Nasralla et al. 2011, by conducting injection studies with deionized water and seawater, demonstrated that former improved oil recovery significantly rather than later. With the purpose of enhancing oil recovery, low salinity water (LSW) with adequate composition and salinity is injected into the reservoir, which changes the wetting properties of the reservoir rock into that favoring oil recovery (Tang and Morrow (1999) and McGuire *et al*. (2005)). Lager *et al*. (2007) in their studies, demonstrated that the effects of low salinity water are linearly proportional to the amount of clay minerals in the rock. There are many theories regarding the mechanisms of wettability alteration in presence of low salinity water. Ligthelm *et al*. (2009) proposed the double layer effect. They suggested that the application of low salinity water results in an expansion of the ionic electrical double layer between the clay and the oil interfaces. This causes the oil to be desorbed from the rock surface thus increasing the water wetness. Another mechanism is that proposed by Tang and Morrow (1996) which attributes wettability changes by decrease in ion binding as microscopic mechanism.

The wettability of the reservoir rock plays an important role in the determination of residual oil saturation and recovery efficiency during the Low salinity water flooding process. Rock wettability can be indicated by using contact angle technique which is measured by several methods such as sessile drop method and Zeta potential.

Fanchi et al.,2010 classified the wettability, in terms of contact angle, as per below.

Selection and peer review by the scientific conference committee under responsibility of the Australian Society for Commerce, Industry and Engineering

Table 1. wettability classification according to Fanchi et al.,2010

Wetting conditions for a water-oil system	
Wetting Condition	**Contact Angle [degrees]**
Strongly water-wet	0-30
Moderately water-wet	30-75
Neutrally wet	75-105
Moderately oil-wet	105-150
Strongly oil-wet	150-180

The injection of low salinity water(<1500ppm) has revealed to improve oil recovery up to 16% of Reserves initially in Place (OOIP) (Zhang et al. 2007). Many Researchers have been more focused on comparative studies between the low and high salinity water, It has been verified that most of them were effective at brine concentration below 5000ppm (Tang and Morrow (1999), Mc Guire et al. (2005), Wideroee et al. (2010), Ramez et al, (2011)).

Wang and Gupta (1995) when investigating the effect of temperature and pressure on wettability, made important observation in that contact angle was not sensitive to pressure changes whereas remarkable changes in wettability were experienced with temperature for the crude-oil/brine/quartz system. Another study that supports change in wettability due to change in temperature was presented by Ramez et al, (2011) who noticed that low salinity water decreased significantly the contact angle as compared to high salinity water. Furthermore, they also concluded that temperature changes affected greatly on contact angle alteration. In addition, the authors suggested that low salinity water injection is potential for improving oil recovery in various ranges of reservoir temperature.

This study investigates the wettability alteration of Berea sandstone rock with brine of different ion composition and salinity in order to understand which ion composition is more effective during LSW flooding.

2. Materials and Methods

2.1 Materials

2.1.1 Cores

In this experiment Berea sandstone core was used. The core was received from the KOCUREK Company (USA) with the properties that are shown in the table 2. It is around 50 years ago that the Berea sandstone rock has been employed for experimental work due to its homogeneity and petro-physical properties. The mineralogy of the rock is presented in the table3.

Tale 2: Properties of core

Product ID	A-101
Formation	Kipton
Permeability	100mD- Brine permeability
Porosity	20%
UCS	6,500-8,000 psi
Dimension	1.5 inch D * 12 inch L

Table 3: Mineralogy of Sandstone Rock

Properties	SiO_2 (Silica)	Al_2O_3 (Alumina)	FeO/Fe_2O_3 (Iron Oxide)	TiO_2 (Titanium Oxide)	CaO (Calcium Oxide)	MgO (Magnesium Oxide)	Alkalies	H_2O (water)	Undetermined	Total
%	86.47	7.31	1.14	0.70	1.21	0.11	1.65	1.20	0.21	100

Figure 1: Sandstone Rock before and after cutting

2.1.3 Crude Oil

The oil must contain polar components, which are naturally occurring surface-active agents, like acids, and bases, which can change the wettability. No effect has been observed by the use of oil free from polar components. The acid number (AN) is another important component. It is defined as the amount of potassium hydroxide (KOH) in milligrams, required for neutralizing 1 g of the petroleum acid in the crude oil, and reversely, the base number (BN) is defined as the amount of KOH in milligrams, required neutralizing 1 g of the petroleum base (Green & Willhite, 1998). When water is present, the oil and rock surfaces become charged. Their polar components behave as acids and bases by giving up a proton and becoming negatively charged, and gaining a proton and becoming positively charged, respectively (Buckley and Liu, 1998). These surface charges influence the adsorption behavior and thus wettability during injection of smart water.
In this, research the crude oil with the following properties used

Table 4: properties of the crude oil

TAN (mgKOH/g)	TBN (mgKOH/g)	Density (g/cm^3)
0.667	0.146	0.821

2.1.2 Brine

In this research, two types of brine were employed

- Formation Water termed "FW" was used for establishing initial and connate water saturations. It was composed of the following ions (Ca^{2+}, Na^+, Mg^{2+}, Cl^-, K^+, HCO_3^-, SO_4^{2-}).
- Low Salinity Water abbreviated "LSW" was prepared with distilled water that contained the (Ca^{2+}, Na^+, Mg^{2+}, Cl^-) with different TDS and concentration.

All Salts were received from the AVANTIS Company (Ipoh, Malaysia). Properties and concentration of all brines shown in table 5.

Selection and peer review by the scientific conference committee under responsibility of the Australian Society for Commerce, Industry and Engineering

Table 5: brine composition and concentration

Composition Name	Na^+ (mg/L)	Ca^{2+} (mg/L)	Mg^{2+} (mg/L)	K^+ (mg/L)	HCO_3^- (mg/L)	SO_4^{2-} (mg/L)	Cl^- (mg/L)	TDS (mg/L)
LSW-1	196.7	0	0	0	0	0	303.3	500
LSW-2	393.4	0	0	0	0	0	606.6	1000
LSW-3	983.5	0	0	0	0	0	1516.5	2500
LSW-4	1376.8	0	0	0	0	0	2123.2	3500
LSW-5	1770.3	0	0	0	0	0	2729.7	4500
LSW-6	2557.1	0	0	0	0	0	3942.9	6500
LSW-7	0	180.6	0	0	0	0	319.4	500
LSW-8	0	361.2	0	0	0	0	638.8	1000
LSW-9	0	903	0	0	0	0	1597	2500
LSW-10	0	1264	0	0	0	0	2236	3500
LSW-11	0	1625	0	0	0	0	2875	4500
LSW-12	0	2347	0	0	0	0	4153	6500
LSW-13	0	0	127.6	0	0	0	372.4	500
LSW-14	0	0	255.3	0	0	0	744.7	1000
LSW-15	0	0	638	0	0	0	1862	2500
LSW-16	0	0	893	0	0	0	2607	3500
LSW-17	0	0	1149	0	0	0	3351	4500
LSW-18	0	0	1659	0	0	0	4841	6500
LSW-19	0	0	0	262.2	0	0	237.8	500
LSW-20	0	0	0	524.4	0	0	475.6	1000
LSW-21	0	0	0	1311	0	0	1189	2500
LSW-22	0	0	0	1835.4	0	0	1664.6	3500
LSW-23	0	0	0	2359.8	0	0	2140.2	4500
LSW-24	0	0	0	3408.6	0	0	3091.4	6500
LSW-25	19.7	18.1	12.8	183.5	0	0	265.9	500
LSW-26	39.4	36.2	178.6	52.4	0	0	693.4	1000
LSW-27	98.6	632	63.8	131.1	0	0	1574.5	2500
LSW-28	965.3	126.4	89.3	183.5	0	0	2135.5	3500
LSW-29	88.8	731.3	516.8	118	0	0	3045.1	4500
LSW-30	511.5	821.6	580.6	341	0	0	4245.3	6500
FW	5923.4	18310.1	12941.3	6818.2	472.2	1318.6	84216.2	130000

2.2 Methodology

Figure 2 shows a schematic drawing of the experimental procedure for wettability measurement. In this investigation, the sessile drop method was used to check the wettability alteration via contact angle measurement. The rock slabs were cut and polished into 3 to 5 mm thin slices. The surfaces of the slices were cleaned with toluene, and dried at 105°C for 24 hours. All slabs were Saturated with formation water (FW) by using the vacuum pump for 2 to 4 hours until no gas bubbles were exiting the core slabs and were put on the oven at temperature of 80 °C for 72 hours. All slabs were removed from FW and aged with Crude oil at an elevated temperature of 80 °C on the oven for about 3 days. Photos were taken from the slabs by using IFT 700 equipment (fig.3) in order to check the wettability condition of each slab before using Low Salinity Water. All slabs were removed from oil and aged with Low Salinity Water (LSW1-30) and Formation Water (FW) at an elevated temperature 80 °C on the oven. To check the wettability alteration it is important to take a photo in specified times of 0, 6, 12 and 24 hours.

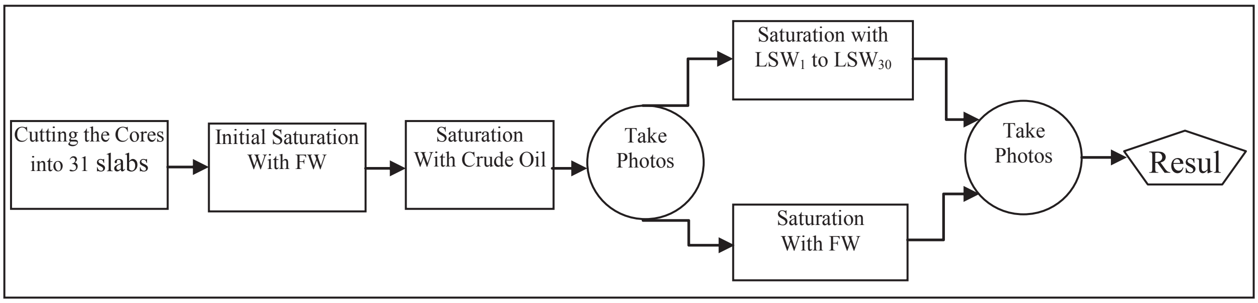


Figure 2: schematic drawing of the experimental procedure for wettability measurement

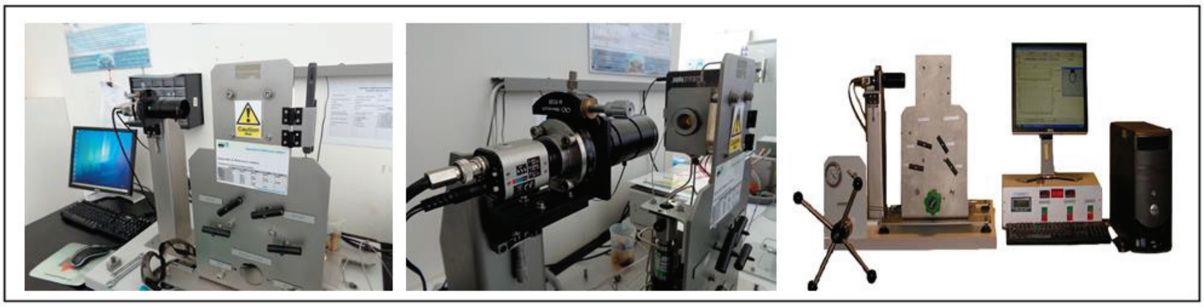
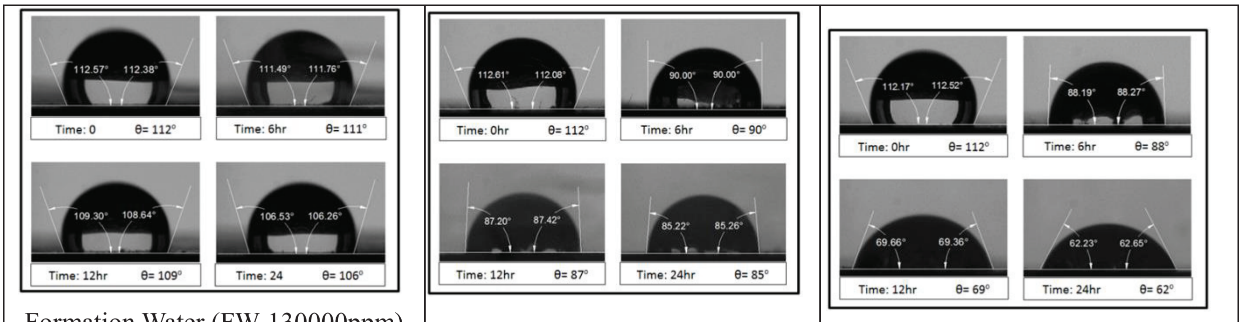


Figure 3: IFT 700 equipment

3. Results and Discussion

The results are presented in form of graphs and contact angle portraits. Figure 4 depicts Contact angle changes in presence of formation water, $MgCl_2$ and KCl. Considerable changes in contact angle are verified for KCl brine composition as compared to $MgCl_2$ both at 500ppm concentration. There is no significant changes in contact angle when in presence of formation water.



Formation Water (FW-130000ppm) LSW-13($MgCl_2$-500ppm) LSW-19(KCl-500ppm)

Figure 4: contact angle changes in presence of formation water, $MgCl_2$ and KCl. (There are many more depictions for contact angle changes at other concentrations and compositions, however for the purpose of this study only the best, least and the constant changes were chosen at 500ppm.)

The preceding results are further discussed from the graphs of figure 5 through 9. For the NaCl Composition, figure 5 illustrates that there are changes in contact angle with time for each NaCl brine concentration. From the figure, it is patent that the contact angle is decreasing with time. Significant changes are experienced at brine concentration ranging from LSW-1 to LSW-6 with that of formation water remaining constant. Large changes in contact angle are at NaCl concentrations of 500ppm and 1000ppm whereby remarkable decrease of contact angle from 112^0 to 73^0 is verified. For KCl brine composition figure 6, there is sufficiently great changes in contact angle with time, from 112^0 to 62.23^0.Relevant changes are noticed for LSW-19 through LSW-24 whereas that of formation water remains constant.

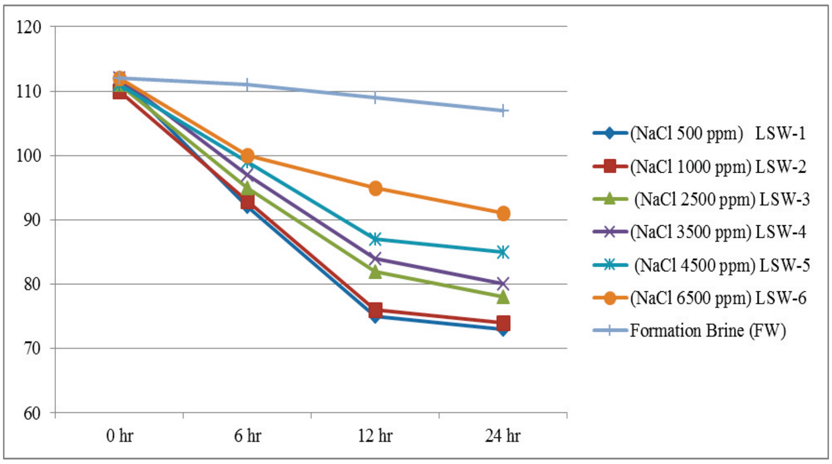


Figure 5 NaCl Brine composition

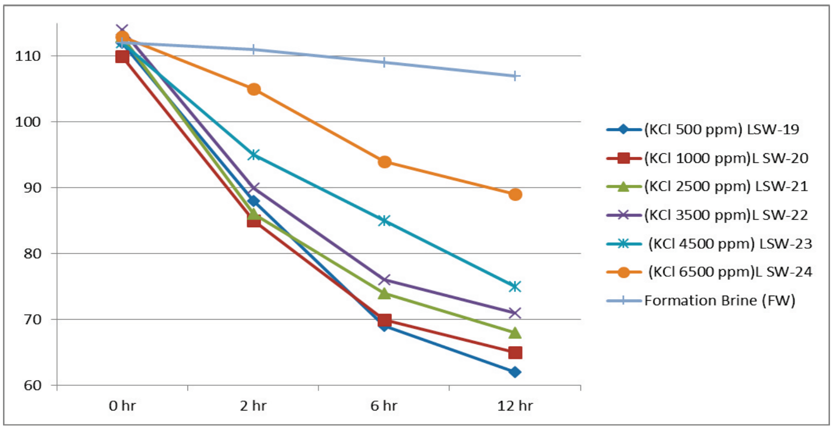


Figure 6 KCl brine composition

Figure 7 is representative of contact angle changes for $MgCl_2$ composition. Here, almost same trends as of foregoing paragraphs are noticed, that is, contact angle decreases with time and distinguishable changes are detected for LSW-13 through LSW-18 and that of formation water undergoing negligible changes. The contact angle changed from around 112^0 to 85^0, which is at lower range than both NaCl and KCl brine compositions. Figure 8 is illustrative of trends for contact angle change when in presence of $CaCl_2$ brine composition. Here, the contact angle decreases with time for each concentration. Notable changes are for LSW-7 through LSW-12 brine concentrations and that of formation brine experiencing no changes. Ideal change in contact angle is experienced at brine concentration of 500ppm and 1000ppm (from 112^0 to 78^0). Finally, when all the brine compositions are mixed, still noticeable changes are present, nevertheless in small range (from 112^0 to 75^0) figure 9. Moreover, greatest changes in wettability are seen at concentrations of the monovalent ions.

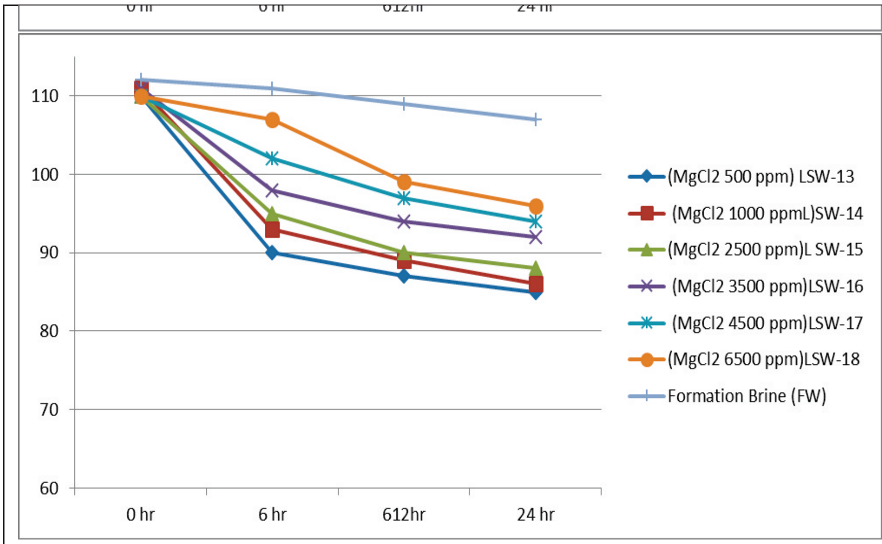


Figure 7 $MgCl_2$ brine composition

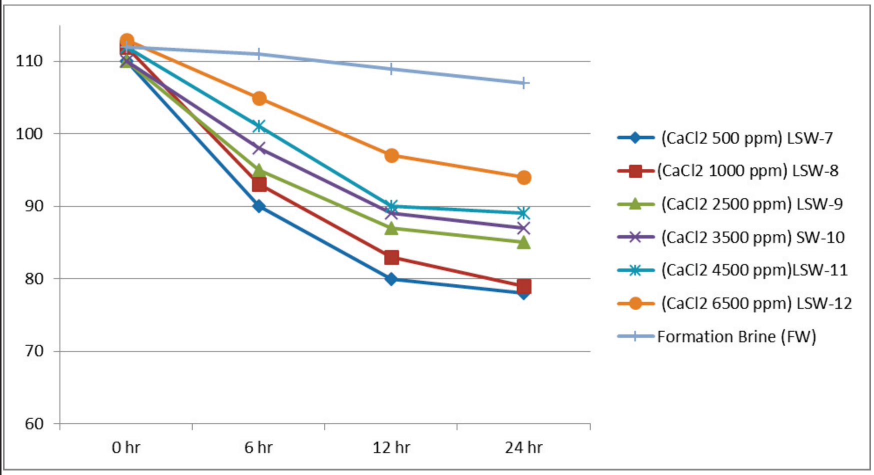


Figure 8 $CaCl_2$ brine composition

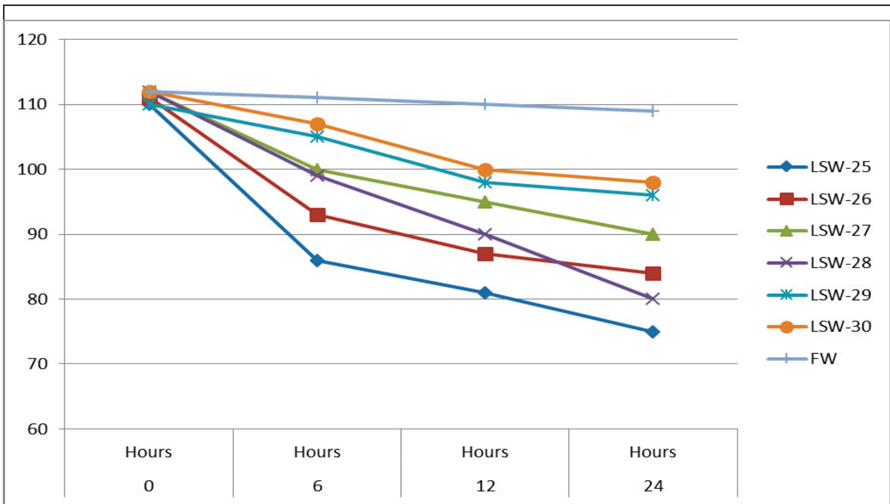


Figure 9 Mixed brine composition

Selection and peer review by the scientific conference committee under responsibility of the Australian Society for Commerce, Industry and Engineering

Overall, outstanding results are noticed for KCl brine composition whereby the contact angle has changed from 112^0 to 62.23^0 at concentrations of 500ppm and 1000ppm followed by NaCl brine composition from 112^0 to 73^0 and finally by the Mixture of all brine compositions which caused changes from 112^0 to 75^0.

4. Conclusion

This study investigated the wettability alteration of Berea sandstone rock with brine of different ion composition and salinity. The experimental results revealed that much change of wettability was experienced by the low salinity water composition of monovalent ion K^+ (from 112^0 to 62.23^0) as compared to other ion compositions such as the monovalent ion of sodium(Na^+), divalent ions (Ca^{+2} and Mg^{+2}) at concentration of 500ppm and formation water at 130000ppm.

Acknowledgements

I would like to acknowledge the supports that I received form Universiti Teknologi PETRONAS. In addition, I would like to thank Associate Professor Dr. Ismail Bin Mohd Saaid Head of Petroleum Engineering Department at Universiti Teknologi PETRONAS for valuable discussions.

References

Fanchi, J.R., 2010. Integrated reservoir asset management: principles and best practices. Elsevier Gulf Professional Publishing, Amsterdam, Burlington, Mass.

Green D.W. and Willhite G.P.:, "Enhanced Oil Recovery", SPE Text Book Series vol. 6, 1998.

Lager, A.; Webb, K. J.; Black, C.J.J. Impact of brine chemistry on oil recovery. Paper A24 presented at the 14th European Symposium on Improved Oil Recovery, Cairo, Egypt, 2007.

Ligthelm, D.J., Gronsveld, J., Hofman, J.P., Brussee, N.J., Marcelis, F. and van der Linde, H.A., 2009. Novel waterflooding strategy by manipulation of injection brine composition. Paper SPE 119835 presented at the 2009 SPE EUROPEC/EAGE Annual conference and exhibition, 8-11 June.

McGuire, P.L, SPE, J.R. Chatham, F.K. Paskvan, D.M. Sommer, SPE, F.H. Carini, "Low Salinity Oil Recovery: An Exciting New EOR Opportunity for Alaska's North Slope,*' Paper SPE 93903 presented at SPE Western Regional Meeting, Mar 30 - Apr 01,2005. Irvine, California.

Nasralla, R. A., Alotaibi, M. B., Nasr-El-Din, II. A., "Efficiency of Oil Recovery by Low Salinity Water Flooding inSandstone Reservoirs," Paper SPE 144602-MS presented at SPE Western North American Region Meeting, 7-11 May 2011, Anchorage, Alaska, USA.

Ramez, |A.N., Bataweel, M.A., and Nasr-El-Din, H.A. (2011). Investigation of Wettability Alteration by Low Salinity. Paper SPE 146322 presented at the Offshore Europe, UK, 6-8 September.

Tang, G. and Morrow, N.R. 1996. Effect of Temperature, Salinity, and Oil Composition on Wetting Behavior and OilRecovery by Waterflooding. Paper SPE 36680.

Tang, G.-Q. and Morrow, N.R., 1999a. Influence of brine composition and fines migration on crude oil/brine/rock interactions and oil recovery. Journal of Petroleum Science and Engineering, 24: 99-111.

Tang, G. and Morrow, N.R., 1999b. Oil recovery by waterflooding and imbibition - Invading brine cation valency and salinity. Paper SCA9911 presented at the International Symposium of the Society of Core Analysts, Golden, CO, USA, 1-4 Aug 1999.

Wideroee, H.C., Rueslaatten, H., Boassen, T., Crescente, CM., Raphaug, M., Soerland, G.H., UrkedaL, H., "Investigation of Low Salinity Water Flooding by NMR and Cryoesem," paper presented at International Symposium of the Society of Core Analysts held in Halifax, Nova Scotia, Canada, 4-7 October, 2010.

Zhang, P., Tweheyo, M.T. and Austad, T., 2007. Wettability alteration and improved oil recovery by spontaneous imbibitionof seawater into chalk: Impact of the potential determining ions: Ca^{2+}, Mg^{2+} and SO_4^{2}-. Colloids and Surfaces A:Physicochem. Eng. Aspects, 301: 199-208.