Contact angle and IFT measurements at elevated temperatures for evaluating wettability in a selected carbonate reservoir in the UAE

Hazim Al-Attar, Jassim Abubacker, Abdurazak Zekri, Mohammad Khalifi,
Essa Lwisa

United Arab Emirates University, UAE

This paper was prepared for presentation at the International Symposium of the Society of Core Analysts held in Snowmass, Colorado, USA, 21-26 August 2016

ABSTRACT

Waterflooding has been regarded as a well-known secondary oil recovery method. In the recent years, extensive research on crude oil, brine, and rock systems has acknowledged that the composition of the injected water can change wetting properties of the reservoir during a waterflood in a promising way to improve oil recovery. Hence, injection of “Smart Water” with correct salinity and composition is considered as a tertiary recovery method. The mechanism behind wettability alteration that is promoted by smart water injection has been a topic of discussion in carbonate and sandstone formations. In this work, some key properties of sea water and its dilutions with natural and spiked sulphate concentrations have been thoroughly investigated in the laboratory. Interfacial tension (IFT) of crude oil/brine system was monitored at ambient and high-pressure/high-temperature (HPHT) conditions. The brine with the least IFT was then used as a non-wetting phase with aged samples of rock for the measurement of contact angle at HPHT conditions. The rock samples are carbonates of a selected onshore oil field in UAE. The results of this work show that sea water of salinity 57,539 mg/l without sulphate spiking may be considered as the Smart Water for further core flooding investigation.

INTRODUCTION

Half of the world’s hydrocarbon reserves is believed to exist in carbonate rocks. The mechanism that governs the recovery should be known for a successful oil production scheme. An important factor that controls the fluid distribution in a reservoir is formation wettability [1,2]. Wettability alteration studies of sea water/oil/rock systems gained momentum after the successful injection of sea water into the highly fractured Ekofisk field in the North Sea [3, 4]. Calcium and Sulphate have been found to exhibit strong potential towards the calcite surfaces [5].

It is the objective of this work to carry out extensive laboratory work on the measurements of IFT and contact angle under HPHT conditions. These two key properties are believed to have direct impact on wettability alteration of crude oil/water/rock systems. Twenty six different brines representing various scenarios of dilution and sulphate-spiking were prepared and tested to identify the Smart Water most effective in the alteration of wettability.

PROCEDURE:

Crude Oil:
Reservoir crude oil from the Asab field was used in all experiments. The dead oil density and viscosity at 20°C are 0.8276 g/cc and 2.93 cp, respectively. The oil is sweet.

Brines:
A total of 26 brines were used in this study including formation water (FW) and injection water (IW) of Asab field. All the brines were prepared using standard procedures reported in Schlumberger manuals. Sea water was collected from the Arabian Gulf and a complete ionic analysis was performed. Sea water of Total Dissolved Solids (TDS) 57,539 mg/l was selected as the base brine and was synthetically prepared in the lab. Different brines were prepared by diluting the sea water and by spiking the sea water with sulphate. Spiking was based on the 885 mg/l of sulphate in formation water. Brines were spiked by 1,770 mg/l (x2 SO_4) and 5,310 mg/l (x6 SO_4). A sulphate spiking of x6 SO_4 was attempted in this work to see how it could alter the IFT and contact angle measurements. Asab oil field has a formation water of TDS 157,488 mg/l with a density of 1.1034 g/ml and viscosity of 1.3483 cp at ambient conditions. The Injection water of this field has a TDS of 258,250 mg/l with a density of 1.1639 mg/l and viscosity of 1.75 cp at ambient conditions. Table 1 shows the ionic composition of SW, FW and IW used in the work.

Core Samples:
Core samples were selected from Asab field. All core samples are limestone.

IFT Measurement:
All Interfacial Tension (IFT) measurements of oil/brine were carried out using Teclis Tracker which utilizes the pendant drop technique. Teclis tracker is capable of running IFT measurements at ambient and HPHT conditions. A cell capable of withstanding HPHT is used. The cell was pressurized to prevent evaporation of brine. A maximum pressure of 248 psia and maximum temperature of 90°C were implemented. The reservoir temperature of 110°C has not been achieved because of equipment limitation.

Contact Angle Measurement:
All contact angle measurements were performed on rock samples aged by fully saturating in Asab crude oil at 90°C and for 3 days, making the rock surface oil-wet with a deduced contact angle of 180°. Alotaibi et al. and Anderson classified wettability in terms of contact angle as being water-wet (0-75°), intermediate-wet (75-115°) and oil-wet (115-180°) [1, 6]. Some contact angle measurements were also carried out for brines of higher IFT values (> 8-10 dynes/cm) at HPHT conditions. All the measurements were continuously monitored for 72 hours.

RESULTS

The IFT values at HPHT conditions are shown in Table 2 and contact angle measurements at end of 72 hrs is shown in Table 3.

DISCUSSION

IFT of Brines at HPHT

Among the three brines in the category IFT 1 in Figure 1, SW corresponds to the least value of TDS and results in the least IFT. The formation and injection water, however, show high values of IFT. There is an increasing trend in IFT for the category IFT 1.

Wang and Gupta, concluded that the increase or decrease of IFT values depends on the composition of the brine [7]. From categories IFT 2 to 5, there is a decreasing trend of IFT. Category 2 shows the effect of sulphate spiking. Combined effect of dilution and sulphate spiking is observed in categories 3 to 5. The three brines in categories 2 to 5, mainly differ in the concentration of sulphate ion and an overall reduction of IFT with sulphate spiking at HPHT can be observed.

From categories IFT 6 to 8, there is an increasing trend of IFT. Categories 6 to 8 show the effect of dilution. So dilution seems to yield an increasing trend of IFT at HPHT conditions for categories IFT 6, 7 and 8. During the dilution of sulphate spiked brines, concentration of potential ions like calcium, magnesium and sulphate were reduced, diluted brines had higher sulphate compared to other ions in the brine. These higher sulphate ions alone, however, were not able to reduce the IFT of diluted brines.

Contact Angle Measurements at Single Temperature and Pressure

The results of the stabilized contact angle measurements after elapsed time of 72 hours are listed in Table 3 and presented in Figure 2.

In category CA 1, Sulphate spiking of the SW makes the rock surface more oil-wet. Also SW ($\Delta\theta = 67°$) was capable of changing the wettability from oil-wet to the border line of intermediate-wet system. In category CA 2, SW/10 ($\Delta\theta = 49°$) changed the wettability from oil wet to weakly oil wet. In category CA 3, SW/50 ($\Delta\theta = 66°$) changed the wettability from oil-wet to border line of intermediate wettability. Categories CA 1 to CA3 show that sulphate spiking increased the contact angle. Hognesen et. al reported that the ratio of calcium to sulphate ion is a key factor in altering the wettability [2]. All measurements were performed at high temperature (90°C). Categories CA 4 and CA 5 show an increasing trend of contact angle with dilution. It seems that calcium-sulphate ratio was not just good enough to alter the wettability. In category CA 6, although the contact angle has decreased but it did not change the wettability from oil wet to intermediate wet.

CONCLUSION

1. The results of IFT measurements at HPHT conditions have shown that SW, its twice and six times sulphate spiking seem to be the three best brines of least IFT. Among these three brines the SW x6 SO_4 brine has shown the least IFT.
2. From the contact angle results at HPHT, the best brines that showed the least contact angle are SW and SW/50. These brines changed the wettability of rock from oil-wet to the border line of intermediate-wet.
3. Sulphate spiking at HPHT conditions has been found to be effective in reducing IFT but not so effective in promoting favorable contact angles.
4. Brine dilution at HPHT conditions failed to reduce the IFT or the contact angle.
5. From above results and economic point of view, SW is the most likely Smart Water which has an IFT of 9.503 dyne /cm at HPHT conditions and a contact angle of 113 degrees ($\Delta\theta = 67°$).

REFERENCES

[1] M. B. Alotaibi, R. Azmy, and H. A. Nasr-El-Din, “Wettability Challenges in Carbonate Reservoirs,” 2010.
[2] E. J. Hognesen, S. Strand, and T. Austad, “Waterflooding of preferential oil-wet carbonates: Oil recovery related to reservoir temperature and brine composition,” 2005.
[3] O. Torsaeter, “An Experimental Study of Water Imbibition in Chalk From the Ekofisk Field,” 1984.
[4] P. Zhang, M. T. Tweheyo, and T. Austad, “Wettability alteration and improved oil recovery by spontaneous imbibition of seawater into chalk: Impact of the potential determining ions Ca2+, Mg2+, and SO42−,” *Colloids Surf. Physicochem. Eng. Asp.*, vol. 301, no. 1–3, pp. 199–208, Jul. 2007.
[5] A. Pierre, J. M. Lamarche, R. Mercier, A. Foissy, and J. Persello, “Calcium as Potential Determining Ion in Aqueous Calcite Suspensions,” *J. Dispers. Sci. Technol.*, vol. 11, no. 6, pp. 611–635, Dec. 1990.
[6] W. G. Anderson, “Wettability Literature Survey- Part 1: Rock/Oil/Brine Interactions and the Effects of Core Handling on Wettability,” *J. Pet. Technol.*, vol. 38, no. 10, pp. 1125–1144, Oct. 1986.
[7] W. Wang and A. Gupta, “Investigation of the Effect of Temperature and Pressure on Wettability Using Modified Pendant Drop Method,” 1995.