INVESTIGATING ENHANCED OIL RECOVERY BY LOW SALINITY WATERFLOODING FROM AN UNCONSOLIDATED SANDSTONE

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ABSTRACT

The focus on Low Salinity Enhanced Oil Recovery (LS EOR) has increased in both laboratory studies and field tests in the last decades. Despite various mechanisms have been suggested to explain how the process works, so far there is no unanimity of view. Using different materials, variations in test procedures and complexity of crude oil/brine/rock (COBR) interaction may contribute to confusion about Low Salinity Effect (LSE). However, finding a consistent mechanistic explanation could help us to predict the reservoirs where the method would have the best chance of working. Due to this significance, the main objective of this study is defined to examine the potential and efficiency of LS EOR from an unconsolidated sandstone. Similarly, this research targets to help in understanding the dominant mechanisms that help in improving oil recovery by LSW. In this study, the natural oil was used to provide more realistic fluid/fluid and fluid/rock interactions. In addition, the high salinity brine (9% NaCl+ 1%$CaCl_2$, 100000ppm) was used to establish the initial water saturation and displacing oil through secondary oil recovery. Moreover, the tertiary recovery process was involved injecting brine with a low salinity (0.1% NaCl, 1000ppm). All the experiments were performed at 40°C and the flow rate of 0.22 ml/min followed by a period of high flow rate (1ml/min) of low salinity brine injection. The samples of the effluent were taken, and produced oil volume, pH, conductivity and density were measured. X-ray diffraction (XRD) analysis revealed the presence of illites on the grain surface of the rock as the main clay materials. From this research a good potential of enhanced oil recovery and the ultimate oil recovery of ~ 4% of OOIP was observed by LSW. Beside this, the results show that low salinity brine injection has two contributing mechanisms for enhanced oil recovery. pH effect and fine migration are the mechanisms that are involved; Both mechanisms are related to alteration of wettability toward more water-wet condition and increasing the oil recovery.

ABSTRAK

Fokus kepada Peningkatan Perolehan Minyak Kemasinan Rendah (LS EOR) telah meningkat di kedua-dua kajian makmal dan ujian lapangan sepanjang dekad yang lalu. Meskipun pelbagai mekanisme telah dicadangkan untuk menerangkan bagaimana proses tersebut berjalan, setakat ini tidak ada kesepakatan pandangan. Menggunakan bahan-bahan yang berbeza, perubahan dalam prosedur ujian dan kerumitan interaksi minyak mentah / air masin / batuan (COBR) boleh menyumbang kepada kekeliruan tentang Kesan Kemasinan Rendah (LSE). Walau bagaimanapun, dengan mencari penjelasan mekanistik yang konsisten ia boleh membantu kita untuk meramalkan takungan di mana kaedah tersebut akan mempunyai peluang terbaik untuk digunakan. Disebabkan oleh kepentingan ini, objektif utama kajian ini dijalankan adalah untuk mengkaji potensi dan kecekapan LS EOR daripada batu pasir yang tidak disatukan. Begitu juga, sasaran penyelidikan ini adalah untuk membantu dalam memahami mekanisme dominan yang membantu dalam meningkatkan perolehan minyak oleh LSE. Dalam kajian ini, minyak semulajadi digunakan untuk memberi cecair / cecair dan interaksi cecair / rock yang lebih realistic. Selain itu, air masin dengan kemasinan yang tinggi (9% NaCl + 1% $CaCl_2$, 100000ppm) telah digunakan untuk mewujudkan ketepuan air permulaan dan menyesarkan minyak melalui perolehan minyak sekunder. Selain itu, proses perolehan tertiari melibatkan suntikan air masin dengan kemasinan yang rendah (0.1% NaCl, 1000ppm). Semua penyelidikan telah dijalankan pada 40 °C dan kadar aliran 0.22 ml / min diikuti dengan tempoh kadar aliran tinggi (1ml/min) suntikan air garam kemasinan rendah. Sampel efluen diambil, dan jumlah minyak yang dihasilkan, pH, kekonduksian dan ketumpatan kemudian diukur. Pembelauan sinar-X (XRD) pula menunjukkan kehadiran illites di permukaan bijian batu sebagai bahan tanah liat utama. Berdasarkan kajian ini, potensi yang baik perolehan minyak dipertingkat dan perolehan minyak utama ~ 4% daripada OOIP telah diperhatikan melalui LSW. Selain itu, keputusan menunjukkan bahawa suntikan air garam kemasinan rendah mempunyai dua mekanisme penyumbang untuk perolehan minyak. Kesan pH dan migrasi halus adalah mekanisme yang terlibat; Kedua-dua mekanisme adalah berkait rapat dengan pengubahan kebolehbasahan lebih ke arah keadaan basah-air dan peningkatan peningkatan perolehan minyak.

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LIST OF ABREVIATIONS

BP	British Petroleum
COBR	crude oil/ brine/ rock
EOR	Enhanced Oil Recovery
IFT	Interfacial Tension
IOR	Improved Oil Recovery
LSE	Low Salinity Effect
LSW	Low Salinity Water Flooding
OOIP	Original Oil In Place
OWI	Oil-Wetting Index
RF	Recovery Factor
STOIIP	Stock Tank Original Oil In Place
SWCTT	Single Well Chemical Tracer Test
WOR	Water Oil Ratio

LIST OF NOMENCLATURES

A	Cross sectional area of porous medium
Ca	Capillary number
D	Displacing phase
K	Permeability
L	Length of porous medium
M	Mobility ratio
q	Flow rate
r	Radius of porous medium
S	Saturating phase
V	Velocity
I_{a-h}	Amott-Harvey wettability index
K_{ro}	Relative oil permeability
K_{rw}	Relative water permeability
m_{dry}	Weight of dried sand pack
m_{sat}	Weight of saturated sand pack
S_{oi}	Initial oil saturation
S_{oir}	Residual oil saturation
S_{orw}	Residual oil saturation
S_{wir}	Irreducible water saturation
S_{or}	Residual oil saturation at each phase of recovery
V_b	Bulk volume
V_o	The volume of oil presented in sand pack prior each flooding stage
V_{oi}	Initial oil volume
V_{op}	Produced oil volume after each phase of waterflooding
V_{osp}	The oil volume displaced by spontaneous imbibition
V_{ot}	The oil volume displaced by both water imbibition and forced displacement
V_p	Pore volume
Vw	The volume of produced water
V_{wsp}	The water volume displaced by spontaneous imbibition
V_{wt}	The water volume displaced by both oil imbibition and forced displacement

W	Wettability
μ	Viscosity of fluids
ϕ	Porosity
ρ_w	Brine density
ΔP	Pressure drop across porous medium
γ	Interfacial tension
γ_{ow}	Interfacial tension between oil and water
γ_{so}	Interfacial tension between solid and oil
γ_{sw}	Interfacial tension between solid and water

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Low Salinity Waterflooding is an Water Base Enhanced Oil Recovery (WBEOR) which was firstly introduced when Bernard (1967) discovered an increased oil recovery by injection of either NaCl brine in the range of 0 to 1% or distillated water. The experiments conducted by injection of different concentration of NaCl brines and fresh water into the sand packs, Berea cores, and outcrop cores from Wyoming after initial oil saturations were established with Soltrol. The experiments indicated that the oil recovery was almost unaffected when the NaCl concentration was in the range of 1 to 15%. The incremental oil recovery was observed when the concentration of NaCl was between 0 to 1 %. The results showed that when hydratbale clays are present a fresh water flood can produce more oil than the brine accompanied by relatively high pressure drops across the cores. The incremental of oil recovery was attributed to clay swelling and plugging of pore spaces available to oil and water. However, this work did not capture the attention of the petroleum industry at that time. The comprehensive set of experiments started in 1990's to confirm the capability of LSW for improving oil recovery in sandstone reservoirs (Jadhunandan and Morrow, 1995; Yildiz and Morrow, 1996; Morrow *et al.*, 1998). Most of the coreflood experiments indicated an incremental oil recovery in both secondary recovery as well as tertiary mode (Zhang *et al.,* 2007; Agbalaka *et al.*, 2009), but sometimes the efficiency observed for only one or the other (Zhang and Morrow, 2006). In some studies incremental oil recovery was never observed (Sharma and Filoco, 2000; Rivet *et al.*, 2010; Skrettingland *et al.*, 2011)

As increasing amounts of laboratory experiment results have been published in the last decade, several field trails have been carried out to evaluate the potential of LSW at the field scale. Webb *et al.* (2004) provided the first field evidence of reduction in residual oil by Low Salinity Effect (LSE). The Log-inject-log tests showed that the residual oil within approximately 4 in. of a wellbore was reduced by up to 60% by use of LSW. The single well chemical tracer test (SWCTT) undertaken in the Alaska (McGuire *et al.*, 2005) which indicate that a substantial reduction of remaining oil saturation from LSW in the range of 6-12% of original oil in place (OOIP). Omar field in Syria showed an incremental recovery of 10-15% of STOIIP due to LSW (Vledder *et al.*, 2010). Powder river basin of Wyoming which have been flooded with water from low salinity sources showed an incremental of oil recovery (Vledder *et al.*, 2010). Moreover, in the North Slope of Alaskan reservoir the oil production rate doubled and a measurable drop in water oil ratio (WOR) was observed; the remaining of oil saturation also decreased from 30% to 20% under LSW (Lager *et al.*, 2008).

Various mechanism have been proposed in the literature to explain the additional oil recovery resulting from low salinity injection. Fine migration (Tang and Morrow, 1999), multicomponent ionic exchange (MIE)(Lager *et al*, 2006), extension of the electrical double (Ligthelm *et al*, 2009) and pH effect (Austad, 2010), are the major mechanisms that proposed by researchers. These mechanisms explain how the oil recovery increases by changing the wettability of the rock from mixed wet state toward more water wet condition in sandstone rocks.

1.2 Problem Statement

Various theories have been proposed to explain the increase in oil production associated with low salinity waterflooding but none of them has so far been accepted as the exact underlying mechanism. Complexity of the minerals, crude oils, and aqueous-phase compositions and the interactions among all these phases are the main reasons for this confusion.

1.3 Objectives

The objectives of this study are to investigate:

- The potential of Low Salinity Waterflooding (LSW) from an unconsolidated sandstone.
- The mechanism(s) contributing in an incremental oil recovery by LSW.

1.4 Scopes of Study

- An unconsolidated sandstone was used as the porous medium. Besides, two different brines including the high salinity brine (9% NaCl+ 1%$CaCl_2$, 100000ppm) and the low salinity brine (0.1% NaCl, 1000ppm) were used. Moreover the natural oil was used in the oil flooding process. All the experiments at the temperature of 40°C and the flow rate of 0.22 ml/min followed by a period of high flow rate (1ml/min) of low salinity brine injection.

1.5 Significant of the Study

Clear understanding of the underlying mechanism of LSW is important in the search for the screening criteria. Finding the criteria could help us to predict the reservoirs performance where the method would have the best chance of working. If the criteria are not available clearly, identifying the optimum salinity and conditions for each method would be difficult for the successful recovery process.

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