EFFECTS OF WETTABILITY AND SALINITY ON MICROBIAL ENHANCED OIL RECOVERY WITH *RHODOCOCCUS* SP. 094

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ABSTRACT
An extensive experimental program consisting mainly of a large number of core-flooding experiments, but also of measurements of fluid properties, interfacial tension and contact angles was carried out to test the effect of wettability and salinity on Microbial Enhanced Oil Recovery (MEOR). 14 water wet and 15 mixed wet bacterial flooding after waterflooding to So_{rWF} were carried out, showing the importance of the distribution of the residual oil. Water wet cores would leave a residual oil saturation after waterflooding of 29% vs. 17,5% for the mixed wet cores, and despite this difference the recoveries from bacterial flooding, based on OOIP were the same for both wettabilities, and 4% higher for the mixed wet cases when recoveries were based on the residual oil saturation after waterflooding. 7 coreflooding experiments were carried out to test the effect of salinity on MEOR. From these experiments it seems that it is possible to further enhance MEOR performance by reducing salinity, but more importantly, that it is possible to control bacterial growth rate by increasing and decreasing salinity. These experiments together with previous work by the authors, such as tests on micromodels, have allowed to further understand how *Rhodococcus* sp. 094 enhances oil recovery, and an update of the proposed mechanism has been made.

INTRODUCTION
In MEOR the growth of oil-degrading bacteria in reservoirs is stimulated to increase the population of bacteria with beneficial properties for mobilizing additional oil. MEOR has lower cost; broader applicability and its associated logistics are simpler than most other EOR methods. Low salinity waterflooding, is a relatively newer EOR technique, despite the fact that historically it has been inadvertently applied when water with lower salinity than connate brine was the most convenient source for injection water. Even with the recent increase in activities both in laboratory research led by Morrow *et al.*[1, 2], and field pilots (especially BP [3, 4] in Alaska's North Slope), not enough data is available to completely discard or confirm some of the main competing theories. However, recent advances point towards complex interactions at the interfaces between the fluids and minerals (especially clays) composing the rocks in the reservoir. These interactions affect the wettability and the distribution of fluids in the reservoir.

Determining the mechanisms responsible for the additional recovery of an EOR method, the extent to which one (or more) of these mechanisms can be acting under different conditions, and to which extent they can increase oil recovery is the key to understanding, predicting and planning EOR projects successfully.

Some of the mechanisms allowing bacteria to improve oil recovery include: reduction of interfacial tension, wettability changes, gas production and conformance control through selective pore blocking. Previous work by the authors [5, 6, 7] have established pore blocking, interfacial tension reduction and wettability changes as the main contributors, and a mechanism has been proposed [8].

The current work studies the effects of wettability and salinity on the efficiency of *Rhodococcus* sp. 094 to recover additional oil. Wettability affects how the different phases are distributed in the porous space, and also the amount of oil that is extracted during waterflooding, both factors that would affect an MEOR process. At lower salinities, bacteria reproduce at a faster rate, which should have an impact on a MEOR recovery process. Even though the effect of salinity was studied by injecting brines with concentrations as low as 300 ppm total dissolved solids (TDS), it has been established in the literature [9, 10] that there is little to no effect of low salinity on synthetic oils. Since the oil used in these experiments is n-dodecane, the lower salinities should only affect the outcome of the experiments through its effects on the bacteria.

EXPERIMENTAL METHODS

Materials

Bacteria: For the wettability experiments, the non-surfactant producing (NSPB) variant of *Rhodococcus* sp. 094 was used, while the surfactant producing variant (SPB), was used for the salinity experiments. Bacterial cell suspensions with bacterial concentrations of $1x10^{-7}$ mL^{-1} were used in the reported experiments. *Rhodococcus* sp. 094 is an alkane oxidizing bacteria capable of forming extremely stable emulsions of crude oil-in-water. It has been described by Bredholdt *et al.*[11] and Crescente *et al.* [5, 6, 7, 8]

Brine: Table 1 shows the used brine (Same as the dodecane medium, omitting the n-dodecane) and bacterial suspensions in brine. For the wettability experiments only 3% brines and bacterial suspensions were used, whereas 3%, 0,3% and 0,03% were used for the salinity experiments.

Hydrocarbon: The hydrocarbon used in all cases was n-dodecane.

Cores: For the wettability experiments a total of 12 Berea core plugs were cut to similar dimensions from four contiguous source cores. The resulting cores were grouped in neighbouring pairs, in which one would be treated to make it mixed wet, and the other would be left in its original water wet state, as shown in Figure 1. The untreated cores were named U1 to U6, and the treated cores T1 to T6. After each experiment the cores were cleaned and dried to reuse, after checking that no significant alteration of the core had occurred. Some of the cores had 4 runs in total.
For the salinity experiments, 7 Berea core plugs were cut from two source cores with similar properties. The resulting plugs were named S1 to S7. These cores had only one run since the low salinity might swell the clays, changing the properties of the cores for subsequent runs. The properties of all cores can be seen in Table 2.

Goniometer: For the interfacial tension (IFT) and contact angle (CA) measurements a goniometer was used. The properties of the studied fluids are shown in Table 3.

Flooding rig: A rig allowing up to five parallel experiments to be carried out was used to perform the corefloodings. The rig is previously described[5, 6].

Methods

In the wettability experiments we changed the wettability of water wet cores by saturating the cores in vacuum with a solution of 10% Surfasil and 90% pentane, and then drying for at least 48 hours at 60 ^{o}C. This procedure changed the wettability from strongly water wet to mixed-wet, as reported by Shabani, *et al.*[7] who measured Amott wettability indices (WI) on core plugs cut from the same source cores used in the current work (Table 2). After each experiment was finished the cores were cleaned in Soxhlet with methanol and toluene, and dried to be reused. A naming convention was established with the formula XYz, where: X is either U for untreated (water wet) or T for treated (mixed wet), Y is a number to identify each core and its pair, and z is a letter (a, b, c…) representing the number of the experiment. The pair U3a and T3a is then the first run of the untreated and treated cores number 3.

The cores were flooded at 1 ml/min in groups of 4 cores, ensuring that pairs were flooded simultaneously. Each core was initially water flooded for at least 10 pore volumes, before switching to NSPB flooding. Not all the corefloodings were successful, as some failed due to pumps not keeping the desired rate, and others due to air coming into the core, however the numbering of the cores still accounts for these failed runs. In total 14 successful runs were made for untreated cores, and 15 for the treated cores.

For the salinity experiment, seven different cases were compared:

1) 3%WF-3%SPB_2: Waterflooding, then secondary bacterial flooding, 3% salinity
2) 3%SPB_1: Primary bacterial flooding, 3% salinity
3) 0,3%WF-0,3%SPB_2: Waterflooding, then secondary bacterial flooding, 0,3% salinity
4) 0,3% SPB_1 Primary bacterial flooding, 0,3% salinity
5) 0,03%WF-0,03%SPB_2: Waterflooding, then secondary bacterial flooding, 0,03% salinity
6) 0,03%SPB_1: Primary bacterial flooding, 0,03% salinity
7) 3%SPB_1-0,3%SPB_2-0,03%SPB_3 Primary bacterial flooding, lowering salinity from 3% to 0,3% and 0,03%

The expected behaviours of these cases can be seen on Figure 2.

RESULTS AND DISCUSSION

The results from the wettability experiments are shown in Tables 4 (water wet cores) and 5 (mixed wet cores) and averages from both kinds of cores are shown in Figure 3. The mixed wet cores had a much higher recovery after waterflooding (WF) (72,9% OOIP) than the water wet cores (57,1% OOIP), and even though So_{rWF} was lower for the mixed wet cores (18,7%) than for the water wet cores (29,3%), the production after bacterial flooding (BF) was the same for the mixed wet case (3,0%) and the water wet case (3,1%), with saturation based on OOIP, with the mixed wet being 4% better than the water wet case when basing the recovery on the So_{rWF} (11,1% for the mixed wet and 7,3% for the water wet case). The fact that recovery is equal in terms of OOIP with a much lower oil saturation after WF indicates that the MEOR mechanism is more effective at mixed wet conditions, which means that the existence of continuous oil films is favourable for MEOR, and conversely, that even at higher saturations, isolated drops of oil are difficult to mobilize. In previous work from the authors [8, 12] it was observed how the oil and bacterial growth distributed differently when comparing oil wet and water wet micromodels.

All the successful wettability floodings are reported in tables 4 and 5, but only those runs where at least one coreflooding from each kind (water wet and mixed wet) were successful are shown in figures, due to space constraints. These results are presented on Figures 4 to 10.

In these figures a general trend of the mixed wet cores having higher recoveries than the water wet cores, already from WF can be observed. This behaviour was seen in all the 13 cases where pairs could be compared (U3a vs. T3a, U4a vs. T4a, and so on). The differences between the recoveries after WF varied between 10% and 20% for most cases. Figure 7 shows a case where this difference was lower than 10% (4% higher for the mixed wet core on the U3c/T3c pair, and 6% on the U4c/T4c). U3c/T3c is also the only case where after BF the water wet core outperformed the mixed wet one (at the final PVi for U3c, T3c had a lower recovery than U3c). Figure 9 shows the other case where the difference of recoveries after WF between water wet and mixed wet cores is lower than 10% (it is 6% in favour of the mixed wet core for the U3d/T3d pair).

The results from the BF curves in the plots varies much more than those of WF, but from the averages in tables 4 and 5 it is clear that when accounting for the lower So_{rWF}, the mixed wet cores performed better by 4% although this difference disappears when basing the recoveries on OOIP. The difference in recovery between water wet and mixed wet cores from WF is, however, much larger than that of BF, so even in those cases where the additional recovery from BF was higher for the water wet cores, the total recovery was still higher on the mixed wet core, except for U3c/T3c.

Figure 11 shows the results from U6a and T6a including pressure. It shows that for a given PVi the pressure is higher for the water wet core. This may be due mainly to the difference of saturations after WF. After starting BF, the pressures seem to increase in parallel, reaching similar final values. This seems to indicate that the selective blocking process is independent from the wettability of the core.

A trend of increasing recoveries after WF with each reuse of the cores is apparent on the water wet cores. On the mixed wet cores the opposite is apparent, but with less consistency. Even though the cores are modified each time a flooding is performed, the data seems to indicate that the wettabilities are unchanged, and despite the increase of recovery from WF for the water wet cores (reducing the remaining oil available to be produced by bacteria), the difference in So_{rWF} between water wet and mixed wet cores is much larger than the differences occurring after each reuse of the cores.

The results from the salinity experiments are presented in Table 6 which shows the final recoveries for the different stages of each experiment, Figure 12 which shows the experiments where SPB has been injected after WF (secondary flooding), and Figure 13 which shows the recovery factor vs. injected pore volumes for the experiments where SPB has been injected from Swi (primary flooding).

The general trend from these plots is consistent with the previous results presented by the authors [6, 7], a comparison of recoveries from the primary SPB compared with WF (of the corresponding secondary SPB flooding) shows that with decreasing salinity SPB goes from performing better than WF at 3% salinity, to perform worse at 0.03%, which indicates that at lower salinities, pore blocking in the near inlet of the core occurs faster.

This has been explained by the hydrophobicity of the SPB which makes the bacteria clump together in large particles that will plug the core at a faster pace. When this is done from the initial conditions, it can mean bypassing oil that would otherwise be produced even by WF. The NSPB variant of the bacteria is not hydrophobic and performs better than SPB as it does not clump so it distributes more efficiently in the porous space before becoming surfactant producing upon contact with oil.

Figure 2-a shows the expected results from bacterial flooding after waterflooding (cases 1, 3 and 5). It is expected that recovery increases with decreasing salinity from WF, and that an additional increase occurs after injecting bacteria at the same salinity as the preceding WF. From Figure 12 it is observed that the results were as expected.

Figure 2-b shows the expected results from primary BF (cases 2, 4 and 6). It is also expected that the lower the salinity, the higher (or faster) the recovery. It is observed in Figure 13 that the cases of primary SPB seem to be unaffected by the initial injection salinity, as the production curves are very similar. This means that increase in the reproduction rate of the SPB or any effect from the lower salinity brines, is overcome by the fast plugging that occurs in the area close to the inlet of the cores.

Figure 2-c shows the expected result for a BF from initial oil saturation, followed by two BFs of lower salinities. It is expected that as salinity lowers, additional oil is recovered. The first flooding from case 7 was expected to be similar to the case 2, 3% SPB. However, it produced more. This is likely due to the fact that the core is from a different batch and has slightly different properties. The general profile of the recovery was as expected increasing with subsequent reductions in injected bacterial suspension salinity, especially with the 0.03% suspension. This shows potential for recovering additional oil in cases where there has been a previous BF.

The interfacial tension (IFT) is not changing significantly with either salinity or when comparing NSPB with SPB. However changes in the interface of oil/brine have been reported in micromodels.[8, 12] The contact angles (CA) show little variation, with all the samples being water wet except for 3% NSPB which was intermediate to water wet.

UPDATE OF THE PROPOSED MECHANISM

An update, based on these results and observations to the proposed mechanism[8] follows:

- Wettability has a great impact on the effectiveness of the bacteria, because it affects the distribution of the remaining oil in the porous space. If the oil forms a continuous connected film it is much easier to move than if it is left in droplet form. Furthermore, droplets have been seen to be engulfed (and immobilized) by bacterial mass[8], which is especially easy if the oil is in small drops.
- This further outlines the importance of introducing bacteria into the porous space in a controlled and well distributed manner. For *Rhodococcus* sp. 094 it means that the NSPB is to be preferred before the SPB, as the more loose initial

distribution of NSPB allows it to distribute deeper into the porous space, seeding more of the remaining oil from the initial moments, and thus changing the interface between oil and brine (and blocking) in a more efficient manner, leaving less oil bypassed, and producing less snap-off than SPB.

- *Rhodococcus* sp. 094 grows faster at lower salinities. This means that in a process where bacteria is growing in the porous space (instead of being continuously injected as the current experimental work, to avoid contamination from additional types of bacteria), and assuming that all other bacterial growth requirements are provided, growth can be accelerated or reduced by changing the salinity of the brine. This can be useful to help initially distribute large quantities of "seeds" deep into the porous space at a high salinity, to later trigger them by reducing the salinity. Additionally, low salinity WF effects may further increase the recovery, if the salinity is low enough.

CONCLUSIONS

The wettability of strongly water wet cores such as Berea can be changed to mixed wet by using the Surfasil/pentane solution, as shown here and by Shabani *et al*.[7] Furthermore, the change seems to resist repeated cleaning with methanol and toluene.

MEOR is more effective in mixed wet cores than on water wet cores, as a consequence of the residual oil being mostly in interconnected films in mixed wet cores vs. dislodged drops in the water wet cores.

The selective blocking effect caused by the bacteria appears to be independent from the wettability of the rock.

There is potential for further increasing recovery from SPB by reducing the salinity of the injected bacterial suspension, and it is also possible to increase recovery from low salinity waterflooding by introducing bacteria at the same salinity.

Blocking of the pores by SPB in the near-inlet region of the cores is apparently increased by decreasing salinity, as it accelerates reproduction rate of the bacteria.

The proposed mechanism has been updated with observations from the current experimental work.

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NOMENCLATURE

PV: Pore volume (ml)
OOIP: Original oil in place
So_i: Initial oil saturation (%) = OOIP*100/PV
Npwf: Total waterflooding production (ml)
Npbac: Total MEOR production (ml)
So_{rWF}: Residual oil saturation after WF (%) = (OOIP-Npwf)*100/PV
%Rwf: % Recovery from WF (%) = Npwf*100/OOIP
%Rtot: Total recovery after MEOR flooding (%) = (Npwf+Npbac)*100/OOIP
%Rbac: % Recovery from MEOR (%) = %Rtot - %Rwf

%Rb$_{Soir}$: % So_{rWF} MIOR Recovery (%) = Npbac*100/(OOIP-Npwf)
So$_f$: Final oil saturation after MIOR (%) = (OOIP-Npwf-Npbac)*100/PV
PVi: Injected pore volumes = (Injected Volume)/PV
OIP$_{WF}$: Oil in place after WF (ml) = OOIP – Recovery (ml)
Recovery BF (% OIP$_{WF}$) = Npbac*100/OIP_{WF}
Recovery BF (% OOIP) = Npbac*100/OOIP
Recovery BF (% $_{WF+BF}$) = (Npwf+Npbac)*100/OOIP

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Table 1 Growth media composition

		Medium concentration			
Component	***Formula***	***Acetate***	***3% NaCl***	***0,3% NaCl***	***0,03% NaCl***
Ammonium Chloride	NH_4Cl	4,6 g/L	0,6 g/L	0,6 g/L	0,6 g/L
Bicine [N,N-bis(2-hydroxyethyl)glycine]	$C_6H_{13}NO_4$	10,0 g/L	10,0 g/L	10,0 g/L	10,0 g/L
Magnesium sulfate-7-hydrate	$MgSO_4$ x $7H_2O$	0,05 g/L	0,05 g/L	0,05 g/L	0,05 g/L
Calcium sulphatedihydrate	$CaSO_4$ x $2H_2O$	0,21 g/L	0,21 g/L	0,21 g/L	0,21 g/L
Potassium Chloride	KCl	0,20 g/L	0,20 g/L	0,20 g/L	0,20 g/L
Sodium Chloride	NaCl	30,0 g/L	30,0 g/L	3,0 g/L	0,3 g/L
Phosphate stock solution [1]		5 mL/L	5 mL/L	5 mL/L	5 mL/L
Trace mineral stock solution [2]		5 mL/L	5 mL/L	5 mL/L	5 mL/L
Sodium Acetate	$NaCH_2COOH$	6,83 g/L			
Dodecane	$CH_3(CH_2)_{10}CH_3$		5,0 g/L	5,0 g/L	5,0 g/L

All media adjusted to pH 8,3 at 30 °C before autoclaving.

Table 2 Properties of studied cores

Core	*Diameter [cm]*	*Length[cm]*	*Pore Volume [cm³]*	*Porosity [%]*	*Permeability [mD]*	*WI**
U1	3.76	6.16	16.50	24.27	322	0.87
T1	3.76	6.16	16.20	24.27	391	-0.01
U2	3.76	6.16	17.00	24.71	442	0.87
T2	3.76	6.16	16.80	24.55	526	-0.01
U3	3.76	6.16	16.50	24.27	375	0.87
T3	3.76	6.16	16.30	23.83	364	-0.01
U4	3.76	6.16	16.60	24.27	541	0.87
T4	3.76	6.16	16.20	23.83	405	-0.01
U5	3.79	6.20	16.10	23.08	292	0.88
T5	3.79	6.10	13.80	20.36	268	0.01
U6	3.79	6.30	16.90	23.74	266	0.88
T6	3.79	5.95	13.90	20.74	226	0.01
S1	3.79	7.30	17.15	20.83	286	-
S2	3.79	7.31	16.80	20.26	323	-
S3	3.70	7.28	16.68	21.30	415	-
S4	3.70	7.27	16.17	20.70	440	-
S5	3.70	7.27	16.67	21.30	425	-
S6	3.70	7.30	16.49	21.00	420	-
S7	3.76	7.40	18.77	22.80	450	-

* Values from Shabani *et al.*[7] from wettabilities in plugs of the same core material

Table 3 Properties of studied fluids

Fluid	*Density [g/cm³]*	*Viscosity [cp]*	*IFT* [mN/m]*	*Contact Angle** [°]*
3% NaCl	1.030	1.04	27.54	53.91
3% NSPB	1.025	1.04	14.82	78.40
3% SPB	1.024	1.04	13.56	51.14
0,3% NaCl	1.012	1.02	30.02	48.32
0,3% SPB	1.009	1.02	15.64	45.83
0,03% NaCl	1.010	1.00	31.81	49.00
0,03% SPB	1.008	1.00	13.72	46.03
Dodecane	0.750	1.47	-	-

*Between brine and dodecane ** Of drop of aqueous solution in dodecane on a quartz plate

[1] The phosphate stock solution contained a mix of 1M $K_2HPO_4 \cdot 3H_2O$ and 1M KH_2PO_4 in a ratio of 8:1.
[2] The trace mineral stock solution contained ($g \cdot L^{-1}$ distilled water): $ZnSO_4 \cdot 7H_2O$ 0.5; $FeSO_4 \cdot 7H_2O$ 0.5; $MnSO_4 \cdot 5H_2O$ 0.5; and concentrated H_2SO_4 1.0 $mL \cdot L^{-1}$.

Table 4 Results from wettability experiments, for water wet cores

Core	*PV [ml]*	*OOIP [ml]*	*Soi [%]*	*Npwf [ml]*	*Npbac [ml]*	*So_{rWF} [%]*	*%Rwf [%]*	*%Rtot [%]*	*%Rbac [%]*	*$\%Rb_{Soir}$ [%]*	*So_f [%]*
U3a	16,20	11,90	73,46	6,70	0,90	32,10	56,30	63,87	7,56	17,31	26,54
U4a	16,40	11,60	70,73	6,70	0,05	29,88	57,76	58,19	0,43	1,02	29,57
U1b	16,50	11,60	70,30	6,50	0,10	30,91	56,03	56,90	0,86	1,96	30,30
U2b	16,10	11,20	69,57	6,60	0,10	28,57	58,93	59,82	0,89	2,17	27,95
U1c	16,40	11,75	71,65	6,30	0,15	33,23	53,62	54,89	1,28	2,75	32,32
U2c	17,20	11,65	67,73	6,50	0,15	29,94	55,79	57,08	1,29	2,91	29,07
U3c	16,60	12,10	72,89	7,30	0,90	28,92	60,33	67,77	7,44	18,75	23,49
U4c	16,60	11,30	68,07	6,90	0,55	26,51	61,06	65,93	4,87	12,50	23,19
U1d	16,60	12,00	72,29	7,40	0,20	27,71	61,67	63,33	1,67	4,35	26,51
U2d	16,90	11,90	70,41	6,95	0,20	29,29	58,40	60,08	1,68	4,04	28,11
U3d	16,60	11,30	68,07	7,30	0,40	24,10	64,60	68,14	3,54	10,00	21,69
U4d	16,90	11,60	68,64	6,60	0,60	29,59	56,90	62,07	5,17	12,00	26,04
U5a	16,10	9,75	60,56	5,05	0,30	29,19	51,79	54,87	3,08	6,38	27,33
U6a	16,90	9,65	57,10	4,50	0,30	30,47	46,63	49,74	3,11	5,83	28,70
Avg	16,57	11,38	68,68	6,52	0,35	29,31	57,13	60,19	3,06	7,28	27,20

Table 5 Results from wettability experiments, for mixed wet cores

Core	*PV [ml]*	*OOIP [ml]*	*Soi [%]*	*Npwf [ml]*	*Npbac [ml]*	*So_{rWF} [%]*	*%Rwf [%]*	*%Rtot [%]*	*%Rbac [%]*	*$\%Rb_{Soir}$ [%]*	*So_f [%]*
T3a	16,10	11,30	70,19	8,30	0,40	18,63	73,45	76,99	3,54	13,33	16,15
T4a	15,90	10,85	68,24	8,80	0,25	12,89	81,11	83,41	2,30	12,20	11,32
T1b	15,80	11,40	72,15	8,90	0,25	15,82	78,07	80,26	2,19	10,00	14,24
T2b	15,90	11,10	69,81	8,60	0,50	15,72	77,48	81,98	4,50	20,00	12,58
T3b	16,00	11,80	73,75	8,40	0,45	21,25	71,19	75,00	3,81	13,24	18,44
T4b	16,00	11,55	72,19	7,80	0,65	23,44	67,53	73,16	5,63	17,33	19,38
T1c	16,60	11,70	70,48	8,75	0,05	17,77	74,79	75,21	0,43	1,69	17,47
T2c	16,80	11,65	69,35	9,00	0,20	15,77	77,25	78,97	1,72	7,55	14,58
T3c	16,30	11,40	69,94	7,30	0,30	25,15	64,04	66,67	2,63	7,32	23,31
T4c	16,30	11,80	72,39	8,00	0,60	23,31	67,80	72,88	5,08	15,79	19,63
T2d	16,80	11,40	67,86	8,30	0,05	18,45	72,81	73,25	0,44	1,61	18,15
T3d	16,60	11,20	67,47	7,90	0,20	19,88	70,54	72,32	1,79	6,06	18,67
T4d	16,60	11,60	69,88	8,55	0,30	18,37	73,71	76,29	2,59	9,84	16,57
T5a	14,80	8,90	60,14	6,30	0,20	17,57	70,79	73,03	2,25	7,69	16,22
T6a	13,90	8,25	59,35	6,00	0,50	16,19	72,73	78,79	6,06	22,22	12,59
Avg	16,03	11,06	68,88	8,06	0,33	18,68	72,88	75,88	3,00	11,06	16,62

Table 6 Results from salinity experiments

	Waterflooding									
Core	***OOIP [ml] (So_i)***	***PVi***	***Recovery***		***OIP_{WF} [ml] (So_{rWF})***	***PVi***	***Recovery Bacterial Flooding***			
			ml	***%***			***ml***	***% OIP_{WF}***	***% OOIP***	***$\%_{WF+BF}$***
S2 3%SPB_2	12,1 (0,72)	104.8	6.3	51.2	5.8 (0.49)	67.9	0.2	3.4	1.7	52.9
S1 3% SPB_1	12,4 (0,73)	-	-	-	-	140.8	6.9		55.2	55.2
S5 0,3%SPB_2	12,1 (0,73)	146.5	7.0	57.9					0.8	58.7
S3 0,3%SPB_1	11,7 (0,74)	-	-	-	-	177.7	6.7		57.7	57.7
S4 0,03%SPB_2	12,0 (0,74)	88.8	7.6	63.5	4.4 (0.36)				1.7	65.2
S6 0,03%SPB_1	12,2 (0,74)					221.1	6.9		56.6	56.6
S7 3-0,3%SPB_1 -0,03%	14,1 (0,75)	118.0	8.6	61.0					1.4 2.1	64.5

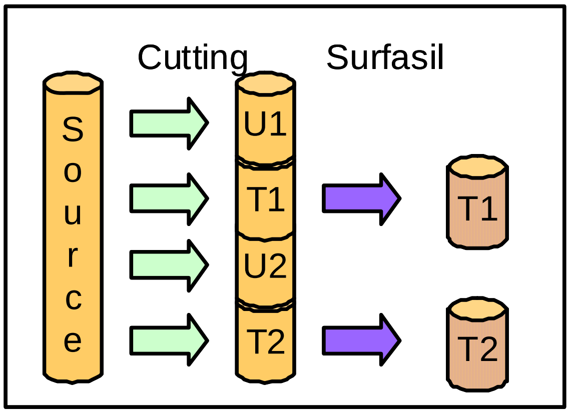
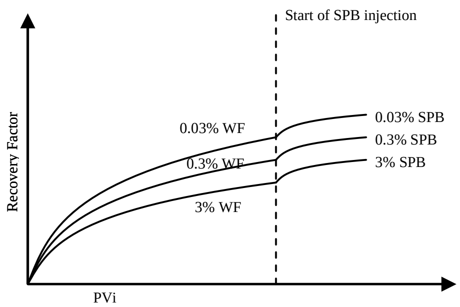
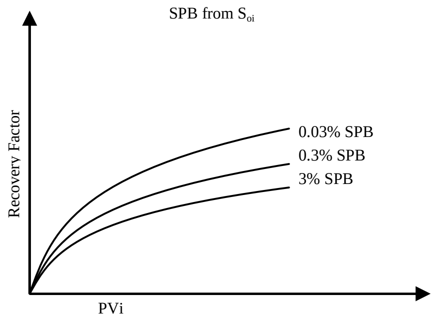


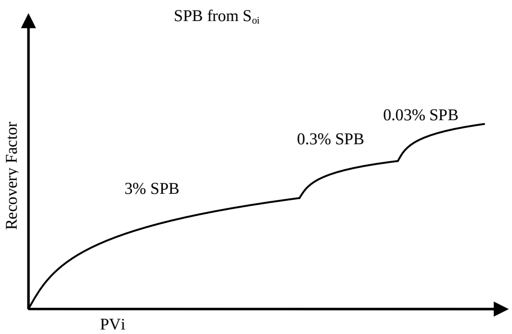
Figure1. Cutting and treatment of the cores to ensure that pairs such as U1 and T1 have similar properties except for the wettability.



a) Waterflooding followed by bacterial flooding



b) Bacterial flooding from the start



c) Bacterial flooding from the start with two salinity decreases

Figure 2. Expected results from the salinity experiment

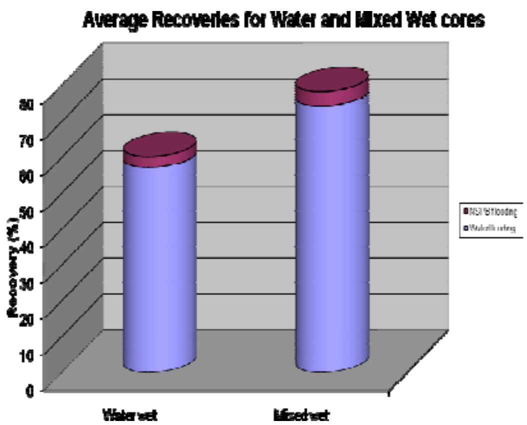


Figure 3.

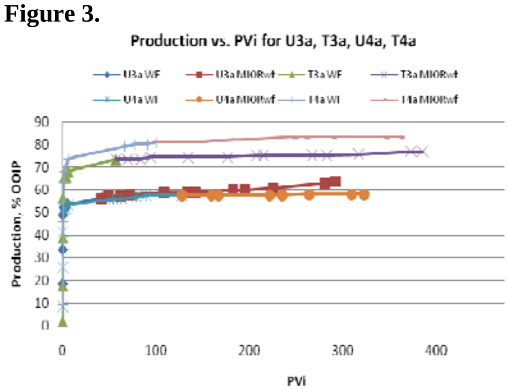


Figure 4.

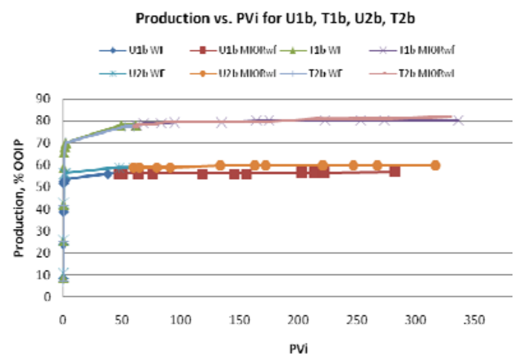


Figure 5.

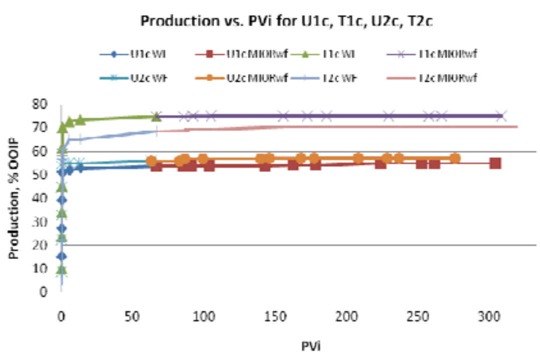


Figure 6.

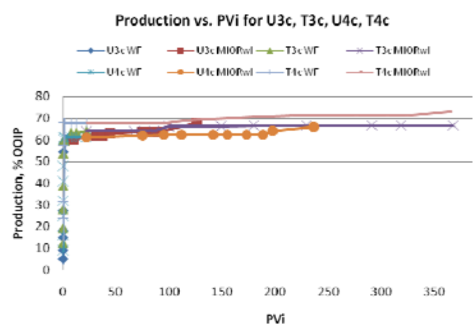


Figure 7.

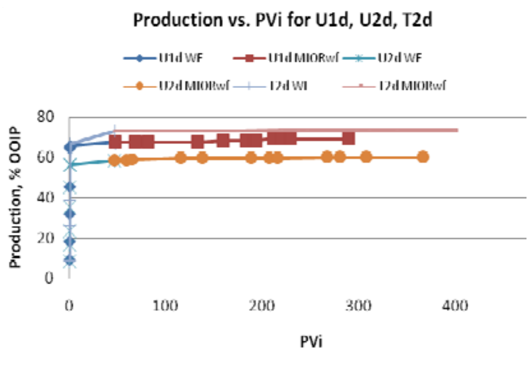


Figure 8.

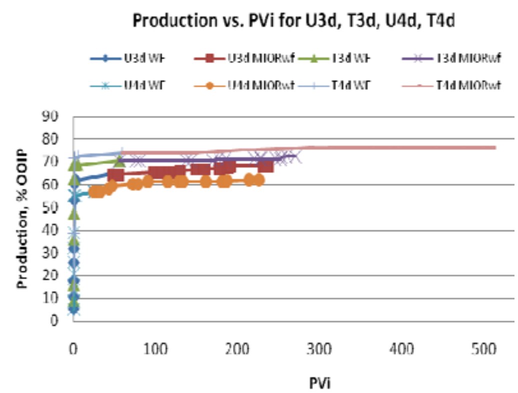


Figure 9.

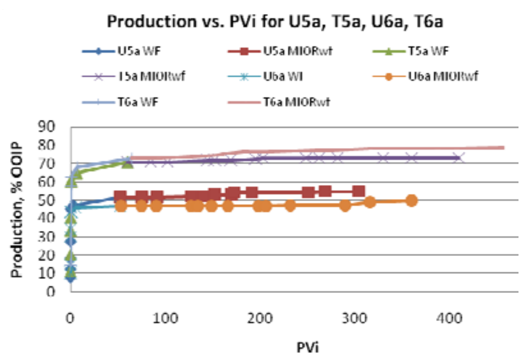


Figure 10.

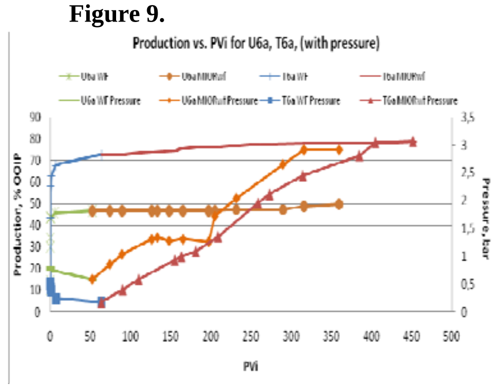


Figure11.

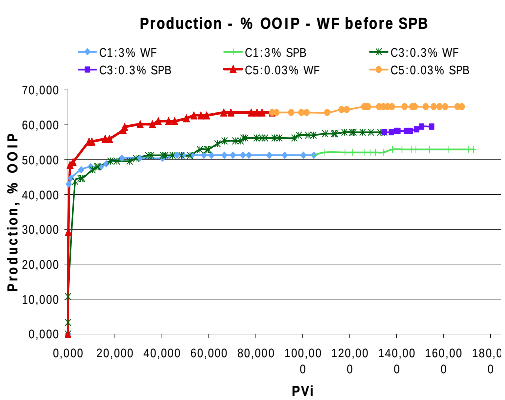


Figure 12. Production vs. PVi for cases 1, 3 and 5 (SPB as secondary flooding)

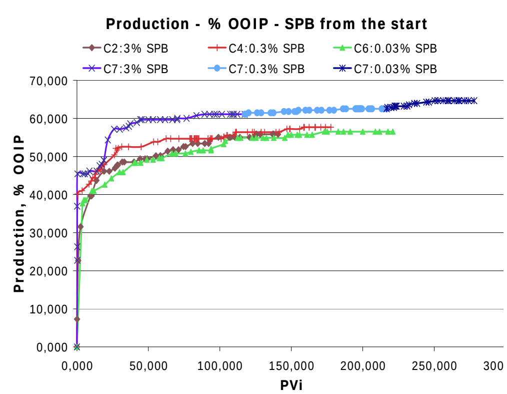


Figure 13. Production vs. PVi for cases 2, 4, 6 and 7 (SPB as primary flooding)