Modeling Mutual Solvent Preflush -The Case of Wettability

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Abstract

This paper presents an in-depth study and analysis of the effect on relative permeability shape on well clean up and squeezes life of a treatment for a Mutual Solvent deployed squeeze treatment.

- *The study revealed that the shape of the relative permeability curve had impact on the well clean up time but the shape of the relative permeability curves do not generally impact greatly on the extent of the squeeze life.*
- *Impact of squeeze life for straight (miscible) relative permeability curves however is greater than for curved (non-miscible) relative permeability's.*

The finding showed that well clean up and squeeze life time is wetting specific, well clean-up time is faster for the strongly water wet system and mix-wet systems than oil wet systems at lower water cuts and/or water saturations but at higher water cuts and saturations the signatures are different. The studies is in its second stage where studies is been done on multi layered cases.

Keywords: Scales, squeeze Treatment, Relative Permeability, wettability

Introduction

As reservoir production decline with increasing water cuts and the need for pressure maintenance which calls for water flooding and as options are considered for such reservoirs to increase recovery and maintain reservoir pressure, there are always bound to be problems with flow assurance. Such needs for pressure maintenance using water floods inadvertently introduce fluid mixing and subsequent reaction of the injected water with both the formation water and with the rock forming minerals. The product of such reactions leads to scales. Scaling is the precipitation of dense, adherent material on metal surfaces and other materials through the action of precipitation of scale-forming salts occurring when solubility's are exceeded because of high concentrations or unfavorable temperatures.

Reservoir pressure depletion, changes in the pH conditions around the wellbore and time of water productionare some typical reservoir conditions which may trigger the formation of scales. Generally as production increases, scale problems become more prevalent as oil and gas reserves are depleted and water production increases. In reservoirs that are supported on a water flood system, scales may occur from the injection facilities to the producing wells right up to the top facilities as well. Whiles many forms of scales are encountered in oilfields around the globe the most common of them all are $CaCO_3$ (Calcium Carbonate) called calcite, and $BaSO_4$(Barium Sulfate) commonly known as barite. Carbonate scales deposition is essentially caused by the presence of calcium and bicarbonate ions in the formation brine, which when the pressure falls may get precipitated as calcite ($CaCO_3$). Sulphate scales however are formed by a result of produced water becoming oversaturated with scale components when two incompatible waters meet down hole. Of critical importance regards sulphate scales is the injection into reservoirs during water flooding operations. Scale can develop in the formation pores near the wellbore reducing formation porosity and permeability. An immediate, effective removal technique is employed whenever scales arise.

The mechanism involves both chemical and mechanical approaches, each with its own niche which largely depends on the location of the scale and its physical properties.Commonly, a scale inhibitor (SI) squeeze treatment is applied to prevent the scale formation in producing wells. Squeeze treatments generally follow the following procedures:

A "spearhead" package usually a demulsifier and/or a surfactant is injected which primarily is believed to increase the water wetness of the formation thereby improving injectivity Highly Diluted inhibitor Preflush follows to push the spearhead into the formation and, in some specific wells aids in cooling the near wellbore region. The main scale inhibitor (SI) treatment usually ranging 2.5% to 20% concentration follows containing the inhibitor chemical. An aqueous or non-aqueous over-flush is injected to push the main treatment to the desired depth in the formation away from the wellbore .A shut-in or soak period (usually 5 - 24 hours) is allowed which is the time when the pumping of the overflush stops and the inhibitor adsorbs (phosphonate/polymers) or precipitates (polymers) onto the rock substrate. Finally, the well is brought back on production. Normally, the main treatment and overflush are injected as aqueous solutions, although in certain scenarios diesel overflush may be deployed instead, which has been studied previously.SI is normally active above a certain concentration, commonly known as MIC, minimum activeinhibitor concentration. The squeeze treatment lifetime is the time at which the SI returned concentration just falls below MIC.In the preflush stage, a mutual solvent or/and a surfactant may be injected. The objective of the preflush is to displace the wellbore fluids, act as a spacer between these fluids and the main treatment stage and clean the formation for enhanced SI retention and to reduce the well clean up time. Surfactants may reduce interfacial tension between fluid phases, which may change the wettability of the formation when the surfactant adsorbs on the rock surface.

Mutual solvent is an additive that is soluble in oil and water with the primary target to minimize the residual water saturation reducing the risk of oil permeability reduction caused by aqueous squeeze treatments. This paper builds up on a previous publication where without changing the residual saturations as a function of wettability nor altering the adsorption as a function of changes in wettability conclusions were made cautiously that the shape of the relative permeability curve between the endpoints values does not significantly affect treatment lifetime.
The focus of this paper will be to consider the impact of the shape of the relative permeability curves between their endpoints effect on preflush mutual solvent on well clean-up time and squeeze life time changing their residual saturations as a function of wettability and altering the adsorption as a function of changes in wettability .
Mutual solvents have been applied in squeeze treatments to reduce the risk of formation damage, generally as a consequence of injecting high volumes of water into the formation. In this section, a sensitivity study is presented, in which the following aspects of applying or not applying a MS preflush are studied:

- Well cleanup time for both MS and NO MS
- Squeeze life time where MS and NO MS is applied

Firstly description is made of the well configurations, then the results of the impact of the shape of the relative permeability on well clean up time and squeeze life time of the squeeze treatment for single layer cases all at high and low water cut are presented.

Well System Configurations

The aspects listed above will be studied in single layer systems at high and low water cut, 95% and 30% respectively. Work on multi-layer systems are currently been studied. The well water cut is defined by the saturation profile in each layer, which depends on the fluid properties, described in **Table 1.**The simplest system consist of a single layer of permeability 100md, height 40ft and porosity 20%. The layer water saturation remains unchanged for all the production stage of 1500 days, i.e. S_w = 47% and 60% for 30% and for 95% water cut values, respectively.

Squeeze Treatment Description

The same treatment is applied in all the cases for both system configurations and water cuts. The treatment consists of the following stages: I). Preflush including a mutual solvent package, ii). aqueous over flushiii) main treatment, where the isotherm describing the retention on the rock formation can be found in **Table 2**iv).6 hours shut-in period and, finally, v).the well is set back on production. All the stages are fully defined in **Table 3**.If the a mutual solvent is present in the preflush state the SI retention capacity will be enhanced, due to the fact that the irreducible oil and water saturations will be reduce, potentially increasing the rock surface available for SI retention.

The model simulates this effect by interpolating the standard isotherm described by the Freundlich isotherms defined in **Table 2**and the enhanced retention, as a function of the extra rock surface. This effect may be reversible in that the SI retention level revertsto the values when MS is not present, or it may be irreversible where SI retention level is maintained at the higher adsorption level associated with the MS, even at lower MS concentrations. In all cases for an MS deployed treatment for this work irreversible effect would be applied to or used.

Single Layer Well Layout Results

In the study below, we present results for a case including a MS Preflushand one without an MS preflush.

Well Clean-Up Time

Well clean-up time is the time necessary to produce oil at the same rate as before the treatment. This corresponds to the time when all the water injected in the squeeze treatment is back produced. To investigate how the MS preflush affects the well cleanup time, the ratio of the total cumulative oil produced versus time both applying and not applying a MS Preflush were studied.

Figure 1 shows the cumulative oil ratio with 30% water cut; since the ratio is below 1 for the first 1.5 days of production, the amount of oil produced where a MS preflush is applied is lower than if it was not applied. After 1.5 days of production, the ratio rises to 1, implying that the well in both strategies is producing at the same oil rate as before the treatment.

The reason why MS preflush shows lower oil production for the early production stage is because of the fact that the MSalters the oil and water relative permeability curves to more straight line (miscible type) functions, and it reduces the endpoint oil and water saturations, $S_{or}$and S_{wc}. This in turn, makes the water saturation profile higher close to the well at the end of the treatment injection stages. Thus at the early stage of production, the water fractional flow will be higher, since only water and oil are present. **Figure 2** compares the water saturation profiles at the end of the treatment injection both with and without MS. It is clear in Figure 2 that the water saturation close to the well is higher for the MS case. The injected water was not transported as deep into the formation for the MS case, which implies that the water will be back produced faster. The same calculations assuming that well water cut was 87% was conducted, which gave the same behavior as for the low water cut case, as shown in **Figure 3**.From **Figure 4**and

Table 4the results shows that the clean-up is faster for the strongly water wet system and mix-wet base case scenario than the oil wet system. It takes about a day for all three systems to reach 50%oil production. Whiles it’s earlier for the total clean up for the well in the strongly water wet system and the Base case mix wet system taking almost a day and a half to reach full production at 100%,it takes about 4 days for the strongly oil wet system to achieve full well clean up to 100% production. From **Figure 5** below we infer that not only does the well clean up time in the base case wetting system(BASECASE) and the Strongly Water Wetting (SWW) system been faster but also they produce much more initial oil per the water-cut and production set than expected. Whiles the Mutual solvent (MS) alters the oil and water relative permeability curves to more straight line (miscible type) functions and reduces the end point oil and water saturations, S_{or} and S_{wi} the resultant effect as described by Vasquez et al is that the water saturation profile close to the well would be higher at the end of the treatment injection stages making water fractional flow higher at the onset of production. In these cases therefore the higher the residual water saturation, the higher would be the fractional flow at the onset of production. While in oil wet systems water would be the free mobile phase this increase in saturation would mean a delayed time for oil flow since as water saturation increases, the relative permeability to oil decreases. From the wetting phases therefore it’s expected that clean up in the SOW phase would be late compared to the SWW phase since water is the free mobile phase in one and oil in the other respectively an increase in water saturation therefore would mean a much time for SOW clean up.

Impact of the Shape of the Relative Permeability Curve on Well Clean-Up Time

Scenario 1: Base Case (curved like Relative permeability curves) and Mix-Wet System (straight line like relative permeability curve)

The studies on these relative permeability curves showed a clear difference in their well clean up time as shown in the **Figure 6**. Whiles the straight relative permeability curve (mixed wet straight line) respond quickly to the onset of production it takes a very long time to clean up.

Notice in Figure 6 that the time to reach 45% of production is quicker in the straight relative permeability curves than in the curved relative permeability for the- Base Case scenario. After the 45% mark the production more or less begins to stabilize in the straight relative permeability curves whiles still peaking in the curved relative permeability.

From **Table 5**below we observe that the water saturation of the base case is higher than that of the mix-wet system. Also the residual water saturation of the base case is higher than the mix-wet system. As a result of these the well cleans up faster in the base case than the mix-wet system with higher residual oil saturation. The early rise and stabilization therefore in the mix-wet system is due to the saturation of oil which is higher than in the base case with water in the immediate larger pores responding to early production and a delayed oil production. There is a quicker response therefore the more miscible the relative permeability curves but an earlier stabilization the less the residual water saturation.This assertion is valid in that the mutual solvent as earlier on explained alters the end point saturations by reducing them making them more mobile and alters the relative permeability curve to more straight line (miscible) type functions .This causes the water saturation to be higher close to the well at the end of the treatment injection phases making the fractional flow of water higher at the onset of production.

From **Figure 7** we observe that at the onset of production the layer saturation of the base case is higher than that of the mix-wet system. The mix-wet systems fractional flow of water is far less at the onset of production compared to the base case because the impact of the MS in altering the mix-wet relative permeability and its end point saturation is far less than for the Base Case. From the initial early rise and higher fractional flow of water it was expected that the cleanup will be late in the Base Case. However in the Base Case the layer saturation is 0.47 higher than that in the mix-wet system hence the injected water is not transported deep into the formation enough compared to the mix-wet system at the early stages of shut-in.

However as the MS makes impact on both relative permeability curves and reduces the end point oil and water saturation there is an increase in water saturation and also the fractional flow of water increases in the near wellbore area for the mix-wet system much more than the base case. As a result it would be back produced very quickly. The mix-wet system has higher oil saturation and thus as water saturation increases the relative permeability to water increases around the well treatment area. Therefore the MS transport in the MIX-WET comparatively would be transported deeper and hence would be expected to have a better squeeze lifetime.

Scenario 2: Oil-Wet Systems

All the four different relative permeability modeled for the oil wet case showed the same trend with reference to the behavior (shape) of the relative permeability curve. As described above in the mix-wet system the same general trend was observed in oil wet systems for straight relative permeability curves and curved like ones.**Figure 8**shows a plot of all the cases well clean up time. We realize that the more straight the relative permeability curves the earlier they begin to produce and stabilize to a late clean up as can be observed for strongly oil wet with straight relative permeability curves in green. Observe the late rise of the strongly oil wet (SOW) but picking up after 45% to produce at a faster rate than the others. A further studies of the oil wet systems showed that the more miscible the relative permeability curves the earlier the production rise but the more time needed for full production at 98% would be achieved. **Figure 9** below shows two cases both oil wet systems with straight relative permeability curves but SOW is more miscible than the oil-wet with straight lines hence it takes a longer time for the well to clean up though SOW with straight lines has an early production rise. This pattern was seen in the Base Case and Mix-wet system as well.

Scenario 3: Water Wet Systems

The behavior of the relative permeability curves in water wet systems also follows the same trend as discussed before. The straight relative permeability curve starts early production but their overall well clean-up time is very late while the strongly water wet starts relatively late but picks up to clean up very early than the others as shown in**Figure 10**.From **Figure11** it takes about 10 days for the straight relative permeability curve to get to about 98% production whiles the strongly water wet takes about a day and a half to get to the same.

Higher Water Cuts -Well Clean Up Time

Figure 12 and **Table 6**shows the well clean-up time of the three cases; Base case, strongly oil and water wet system.

At higher water cuts the layer saturation in strongly oil wet systems increases making the relative permeability to oil very less than at lower water cuts hence production of oil is very low. The effect of the MS and the increased layer saturation causes the fractional flow of water to increase to higher levels therefore clean up time for SWW is very delayed compared with the base case that cleans up early. Comparing Table 4 and 6 for the strongly oil wet system it takes about three times the same amount of days for the well to clean up in the higher water cut case than in the lower water cut case for production to rump up to 50% and 5 times the same amount of days to reach to 90% production. In the strongly water wet case from Table4 and 6 , it takes six times the same day to reach 90% production for the higher water cut case. Obviously this is representative of a combining effect of the mutual solvent in mobilizing the residual saturations and a flooding system that makes the layer saturation excessively high.

Impact of the shape of the relative permeability curve on well clean-up time for higher water cut cases
Scenario 1: Base Case (curved like Relative permeability curves) and Mix-Wet System (straight line like relative permeability curve)

From**Figure 13**we notice that whiles in the lower water case it took the base case few days to ramp up to 100% production; in the higher water-cut case it rather takes the base case longer time to clean up than the mix-wet case. It takes almost a day for both to get to 50% production; whiles SOW takes almost a day and a half to reach 90% production it takes 5.5 days for the mix-wet to achieve the same. Likewise it takes the mix-wet 6 days to achieve full 100% production and the base case 20 days to achieve the same. The residual water saturation for the base case is higher than that of the mix-wet system and the water saturation is also higher hence the early cleanup it shows for the first 2 days is in line to reach 90% oil production earlier than the mix-wet system. However with MS impact the residual saturations are mobilized and the fractional flow of water increases hence more water are produced than that of the mix-wet system which has a lower residual water saturation and layer water saturation. Fractional flow of water therefore after the 90% mark increases in the Base case making it take time to cleanup fully. However that of the mix-wet would be low and hence ramps up to the full production mark.

Scenario 2: oil wet system

From **Figure 14** we observe that cleanup for oil wet-1 is faster than the SOW and the oil wet-2. The oil wet-1 has higher water saturation than the SOW and the Oil wet-2. In oil-wet systems therefore the greater the residual water saturation the faster the well clean up for the higher water cut cases. Unlike in the case of the mix-wet systems above the regards the shape of the relative permeability curves to well clean up times in oil wet cases the more curve like the relative permeability curves the earlier the well clean up time whiles it takes a long time for the straight like ones to cleanup.

Scenario 3- Water Wet Systems

Figure 15 shows the higher water case for the three water wet systems. Observe that here the water wet-2 cleans up faster than the SWW which was not so in the lower water cut scenario. As has been discussed earlier in the oil wet cases the same trend follows for the water wet cases as well. Again here it takes about three and a half times the same number of days to clean up for straight relative permeability curves than in lower water cuts but in the mix-wet and oil wet cases it took about three times making clean up for the water wet case much delayed for straight relative permeability. From the discussions of the lower water-cut cases and the higher water-cut cases and the trend realized throughout we can conclude that the well clean up time is very dependent on the relative permeability curves behavior and residual saturation each have.i.e. Well clean up time is wetting specific. There is a quicker response for the more miscible relative permeability curves but generally they clean up late whiles curved relative permeability have a quicker clean up time generally. The signatures shows that at lower water cut the higher the residual saturation the faster the well clean up and at higher water cut the lower the residual saturation the faster the well clean up time for relative permeability curves that are curved like in behavior.

However for straight line like more miscible systems it takes about three times the same amount of days to clean up in higher water cut scenarios than they do in lower water cut cases but they generally have an earlier production before they stabilize and rise again to achieve 98% plus full production.

Lower Water cuts-Squeeze Life Time

Comparing all the results in Table 7 and 8 it’s clear that the mutual solvent does help increase squeeze life, the Base case without MS has a squeeze life of 22 and with MS of 32 months. Obviously with mutual solvent it’s expected that the surface area for adsorption would be greater than without and hence better squeeze life time. Firstly the results reveal that the impact of the mutual solvent on the oil wetting system is lesser than that on the water wet systems. This can be attributed to the fact that the inhibitor is more soluble in the aqueous phase-water wetting phase than in the non-aqueous –oil wetting phase. As the inhibitors adsorbs onto the rock during shut –in, in water wet systems there is much more adsorption since a greater surface area of rock is exposed to the aqueous SI solution than in oil wet systems. Again inhibitor returns in oil-wet systems is faster than water wet ones.The second observation has to do with the relative permeability curves behavior. From the result in Table 7 and8we observe that without mutual solvent, B1-mildly oil wet 1 case had a squeeze life of 27 months whiles SOW was 28months.With MS, case B1-mildly oil wet-1 had a squeeze life of 31.5 months and SOW had 31.3 months. However both case B1-mildly oil wet -1 and SOW have curved like relative permeability curves. Comparatively case B1-mildly oil wet -2 has a straight line like relative permeability curve and responds better to MS with a squeeze life of 31.4 whiles without MS it had a squeeze life of 22 months. We also observe that the more curved like the relative permeability curves is the better squeeze life in oil-wetting systems without mutual solvent Preflush. However with mutual solvent Preflush the effect on strongly oil wetting systems is very minimal compared to slightly or mildly wet oil systems. Again we realize that not all the relative permeability curves respond to mutual solvent Preflush to the same degree. In the water wet systems they almost all have same response whether the relative permeability curves are straight like or curvy in nature but in oil wet systems the more straight the relative permeability curves the better the response to mutual solvent Preflush and the better the squeeze life. **Figure 16**shows clearly the return concentrations for oil wet-2 cases with and without MS squeeze life time. Similar results were also seen for the higher water cut cases. From Figure 9 and 10 for the higher water case scenario the same observation is seen but particularly we observe that the impact of MS on higher water cut scenarios are far less than at lower water-cut cases . From the discussion so far on lower and higher water cuts we can conclude that the shape of the relative permeability curves do not generally impact greatly on the extent of the squeeze life. However it can be deduced that squeeze life is wetting specific since the impact of MS on oil and water wetting systems showed remarkable difference in the response to MS treatment.

Conclusions

In this paper, a near-well design model was used to study the effects of including a mutual solvent (MS) package in thepreflush stage of a scale inhibitor squeeze treatment. The effect of the MS package was studied on (i) the oil Flow rate which gives an estimation of well cleanup time, (ii) the pressure drop, and (iii) the squeeze treatment lifetime. These effects were studied in single layered near well systems, for high and low well water cut cases. The results demonstrate that applying MS preflush, the well cleanup time will be slightly longer than without it. However, oil production rate with and without MS preflush show the same value after a couple of days of production. This is due to the fact that the MS make the water and oil relative permeability more miscible like (straight lines) and both end-point oil and water saturation are reduced (to $S_{or} = S_{wc} = 0$, in this case). This has the dual effect of increasing the water fractional flow at a given water saturation and also of increasing the water saturation itself in the near wellbore area. As Vasquez et al demonstrates that although, it seems that the well clean-up time will be slightly longer using MS preflush, the pressure drop necessary to produce at a certain rate is lower, due to the fact that the fluid mobility is increased. This might be very positive in the early stage of production, when the well is set back in production. From the discussion on lower and higher water cuts conclusion can be made that For an MS deployed squeeze treatment the well clean up time is dependent on the relative permeability curves behavior and residual saturation each have.Also the shape of the relative permeability curves does not generally impact greatly on the extent of the squeeze life. However it can be deduced that squeeze life is wetting specific since the impact of MS on oil and water wetting systems showed remarkable difference in the response to MS treatment.Impact of squeeze life for straight relative permeability curves however is greater than for curved relative permeability’s. Whiles these results may be fairly good for extrapolating it should be taken cautiously.

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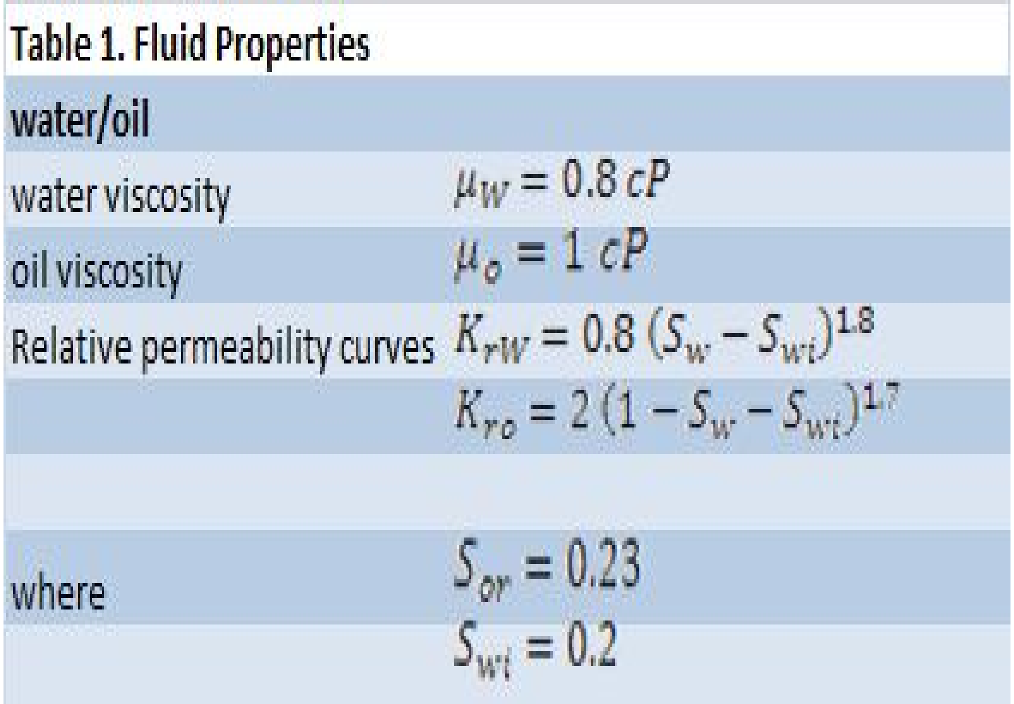

Table 1. Fluid Properties

water/oil	
water viscosity	$\mu_W = 0.8\,cP$
oil viscosity	$\mu_o = 1\,cP$
Relative permeability curves	$K_{rW} = 0.8\,(S_w - S_{wi})^{1.8}$
	$K_{ro} = 2\,(1 - S_w - S_{wi})^{1.7}$
where	$S_{or} = 0.23$
	$S_{wi} = 0.2$

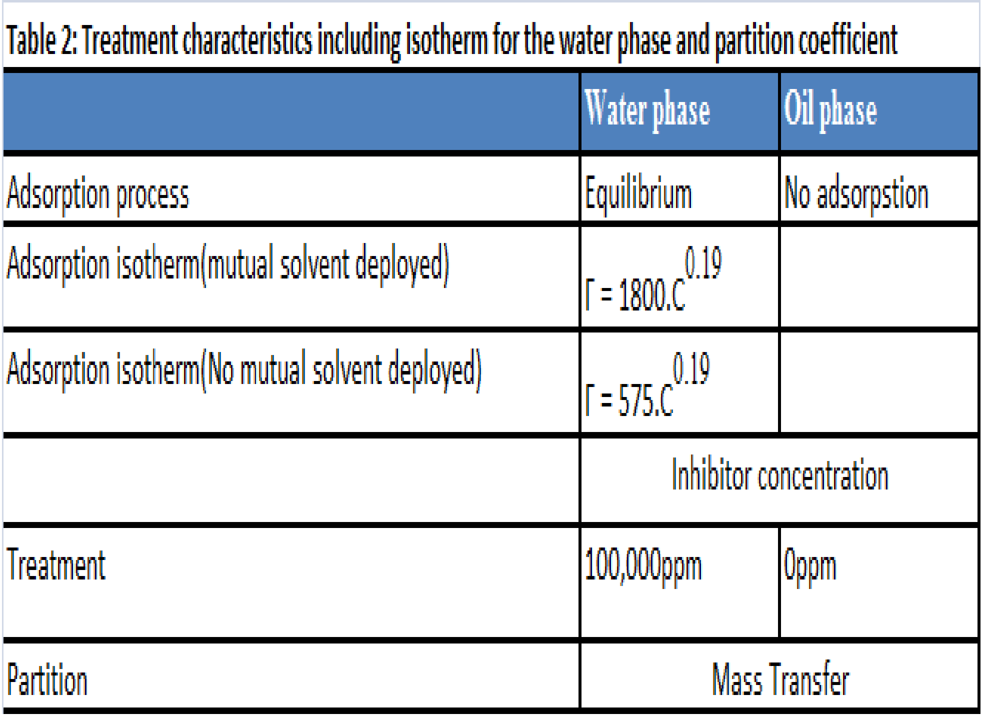

Table 2: Treatment characteristics including isotherm for the water phase and partition coefficient

	Water phase	Oil phase
Adsorption process	Equilibrium	No adsorpstion
Adsorption isotherm(mutual solvent deployed)	$\Gamma = 1800.C^{0.19}$	
Adsorption isotherm(No mutual solvent deployed)	$\Gamma = 575.C^{0.19}$	
	Inhibitor concentration	
Treatment	100,000ppm	0ppm
Partition	Mass Transfer	

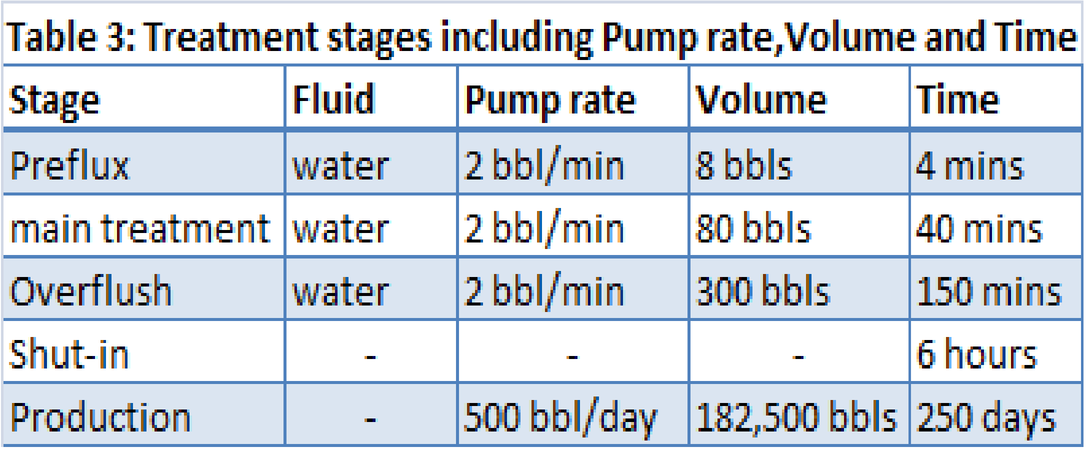

Table 3: Treatment stages including Pump rate,Volume and Time

Stage	Fluid	Pump rate	Volume	Time
Preflux	water	2 bbl/min	8 bbls	4 mins
main treatment	water	2 bbl/min	80 bbls	40 mins
Overflush	water	2 bbl/min	300 bbls	150 mins
Shut-in	-	-	-	6 hours
Production	-	500 bbl/day	182,500 bbls	250 days

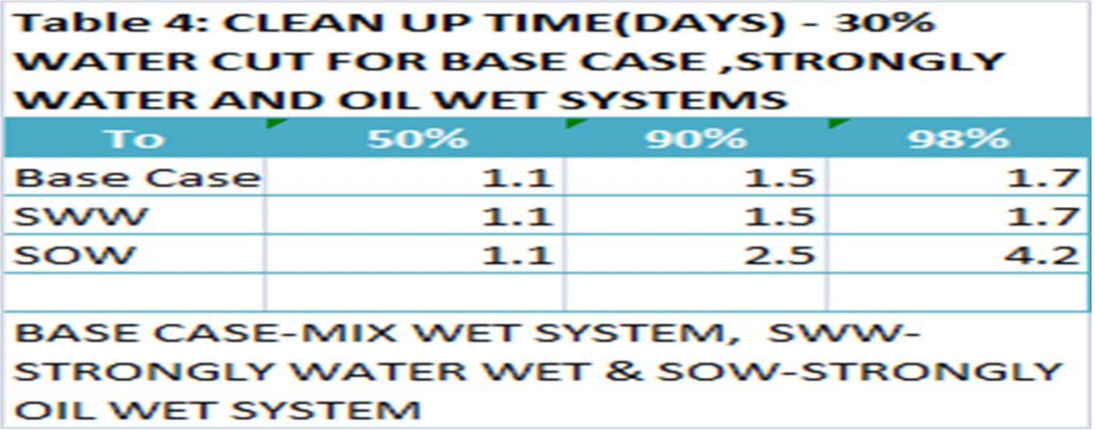

TABLE 4: CLEAN UP TIME(DAYS) - 30% WATER CUT FOR BASE CASE ,STRONGLY WATER AND OIL WET SYSTEMS

To	50%	90%	98%
Base Case	1.1	1.5	1.7
SWW	1.1	1.5	1.7
SOW	1.1	2.5	4.2

BASE CASE-MIX WET SYSTEM, SWW-STRONGLY WATER WET & SOW-STRONGLY OIL WET SYSTEM

*In Table 4 above the cases are done without mutual solvent addition and with no alteration to the adsorption isotherm coded “No” in the table whiles that in Table 5 are done with mutual solvent addition and with alteration to the adsorption isotherm coded “YES”. In Table 4 and 5 “Yes” in the table means that the simulations are run changing the residual saturations as a function of wetability (RSaW)

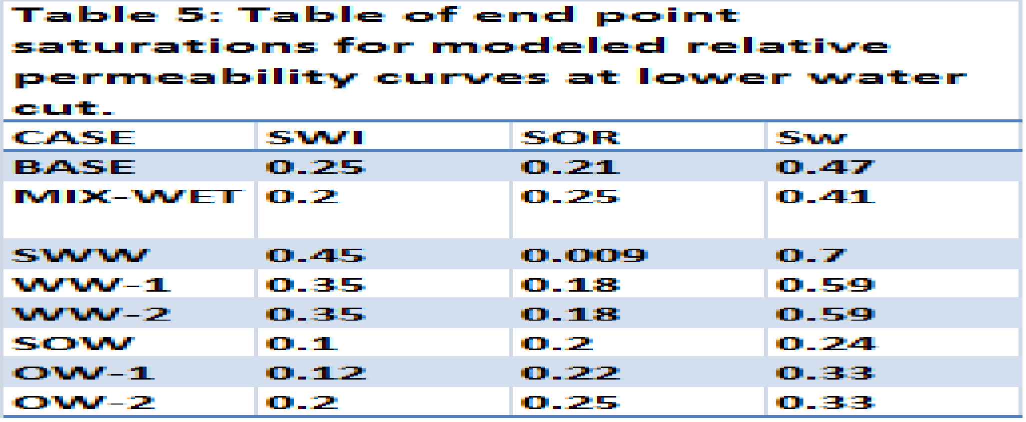

Table 5: Table of end point saturations for modeled relative permeability curves at lower water cut.

CASE	SWI	SOR	Sw
BASE	0.25	0.21	0.47
MIX-WET	0.2	0.25	0.41
SWW	0.45	0.009	0.7
WW-1	0.35	0.18	0.59
WW-2	0.35	0.18	0.59
SOW	0.1	0.2	0.24
OW-1	0.12	0.22	0.33
OW-2	0.2	0.25	0.33

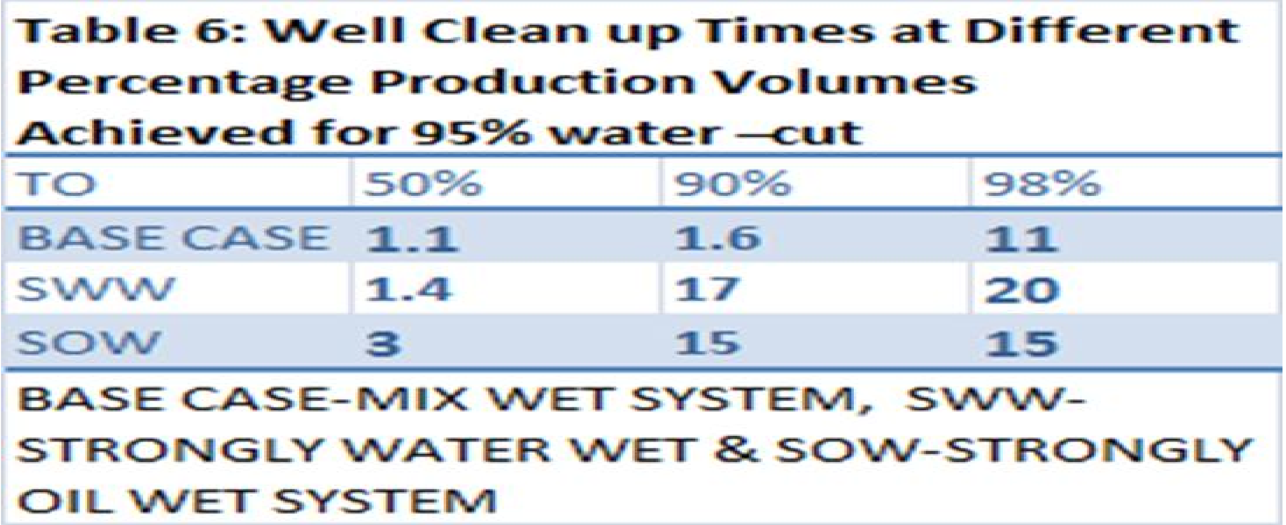

Table 6: Well Clean up Times at Different Percentage Production Volumes Achieved for 95% water –cut

TO	50%	90%	98%
BASE CASE	1.1	1.6	11
SWW	1.4	17	20
SOW	3	15	15

BASE CASE-MIX WET SYSTEM, SWW-STRONGLY WATER WET & SOW-STRONGLY OIL WET SYSTEM

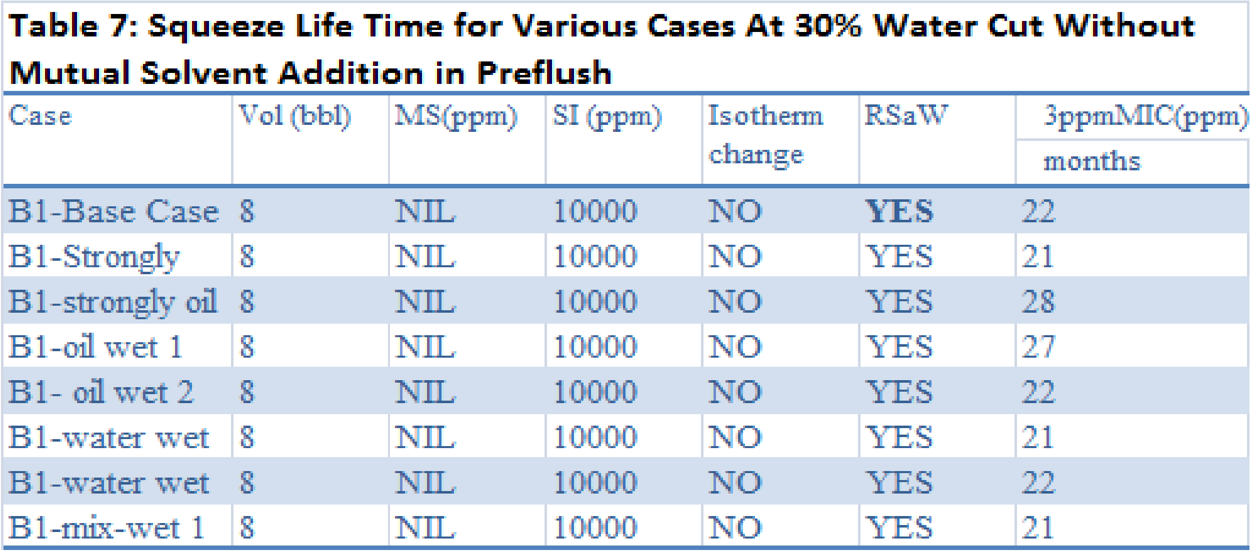

Table 7: Squeeze Life Time for Various Cases At 30% Water Cut Without Mutual Solvent Addition in Preflush

Case	Vol (bbl)	MS(ppm)	SI (ppm)	Isotherm change	RSaW	3ppmMIC(ppm) months
B1-Base Case	8	NIL	10000	NO	YES	22
B1-Strongly	8	NIL	10000	NO	YES	21
B1-strongly oil	8	NIL	10000	NO	YES	28
B1-oil wet 1	8	NIL	10000	NO	YES	27
B1- oil wet 2	8	NIL	10000	NO	YES	22
B1-water wet	8	NIL	10000	NO	YES	21
B1-water wet	8	NIL	10000	NO	YES	22
B1-mix-wet 1	8	NIL	10000	NO	YES	21

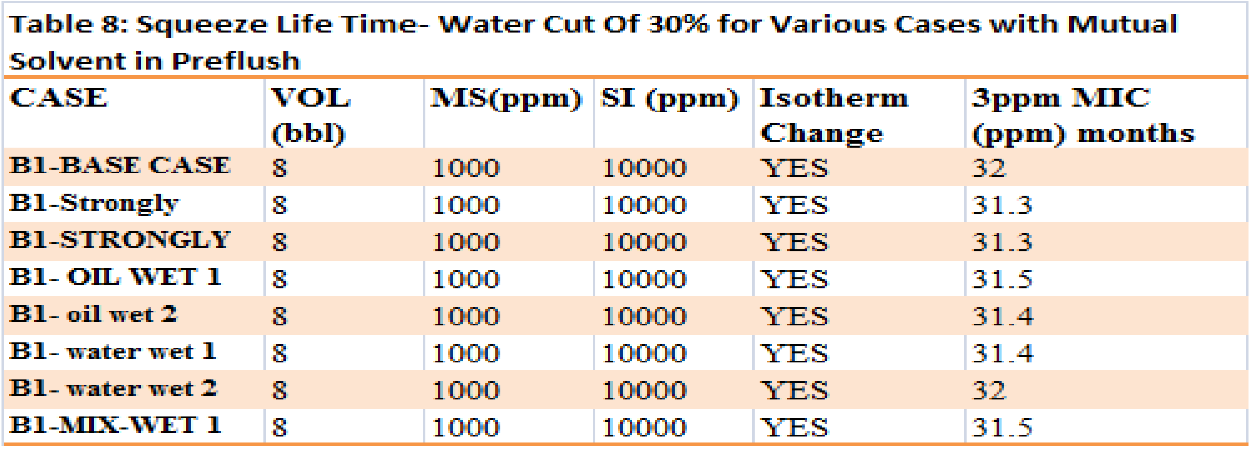

Table 8: Squeeze Life Time- Water Cut Of 30% for Various Cases with Mutual Solvent in Preflush

CASE	VOL (bbl)	MS(ppm)	SI (ppm)	Isotherm Change	3ppm MIC (ppm) months
B1-BASE CASE	8	1000	10000	YES	32
B1-Strongly	8	1000	10000	YES	31.3
B1-STRONGLY	8	1000	10000	YES	31.3
B1- OIL WET 1	8	1000	10000	YES	31.5
B1- oil wet 2	8	1000	10000	YES	31.4
B1- water wet 1	8	1000	10000	YES	31.4
B1- water wet 2	8	1000	10000	YES	32
B1-MIX-WET 1	8	1000	10000	YES	31.5

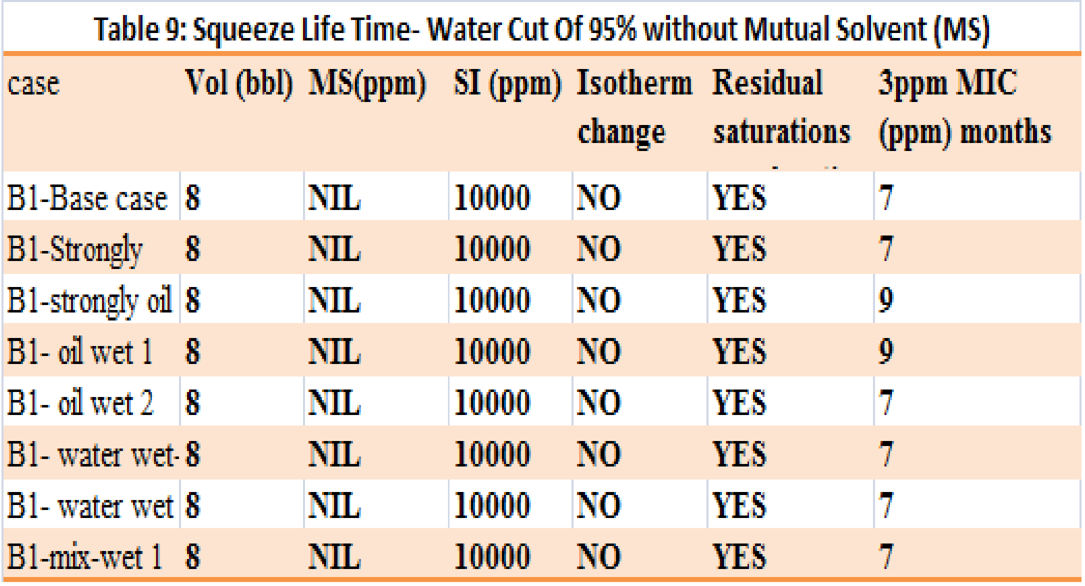

Table 9: Squeeze Life Time- Water Cut Of 95% without Mutual Solvent (MS)

case	Vol (bbl)	MS(ppm)	SI (ppm)	Isotherm change	Residual saturations	3ppm MIC (ppm) months
B1-Base case	8	NIL	10000	NO	YES	7
B1-Strongly	8	NIL	10000	NO	YES	7
B1-strongly oil	8	NIL	10000	NO	YES	9
B1- oil wet 1	8	NIL	10000	NO	YES	9
B1- oil wet 2	8	NIL	10000	NO	YES	7
B1- water wet-	8	NIL	10000	NO	YES	7
B1- water wet	8	NIL	10000	NO	YES	7
B1-mix-wet 1	8	NIL	10000	NO	YES	7

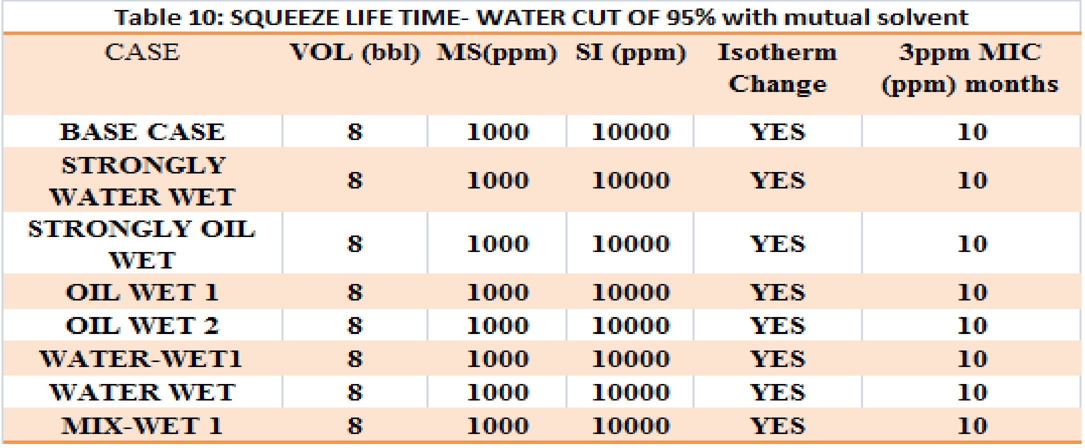

Table 10: SQUEEZE LIFE TIME- WATER CUT OF 95% with mutual solvent

CASE	VOL (bbl)	MS(ppm)	SI (ppm)	Isotherm Change	3ppm MIC (ppm) months
BASE CASE	8	1000	10000	YES	10
STRONGLY WATER WET	8	1000	10000	YES	10
STRONGLY OIL WET	8	1000	10000	YES	10
OIL WET 1	8	1000	10000	YES	10
OIL WET 2	8	1000	10000	YES	10
WATER-WET1	8	1000	10000	YES	10
WATER WET	8	1000	10000	YES	10
MIX-WET 1	8	1000	10000	YES	10

Figures

Figure 1: Example of a pipe with mixed BaSO4 and CaCO3 Scale from the North Sea. Courtesy E.J. Mackay andK.S. Sorbie. SPE 56775, October 1999.

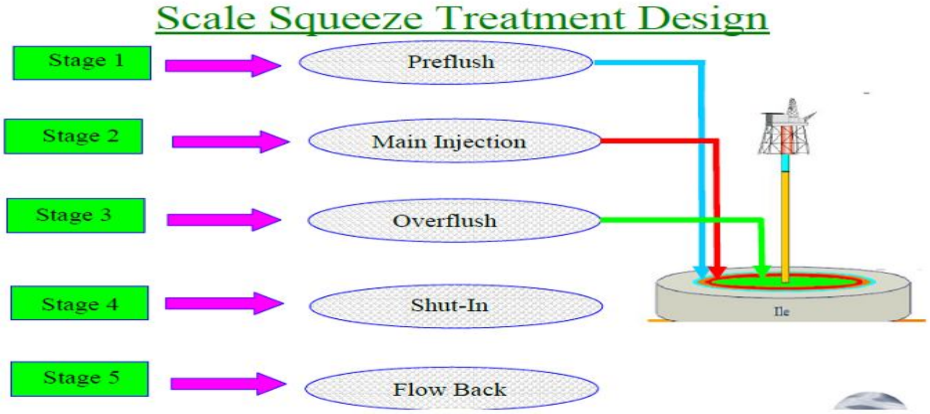

Figure 2: A typical schematic of Squeeze treatment design

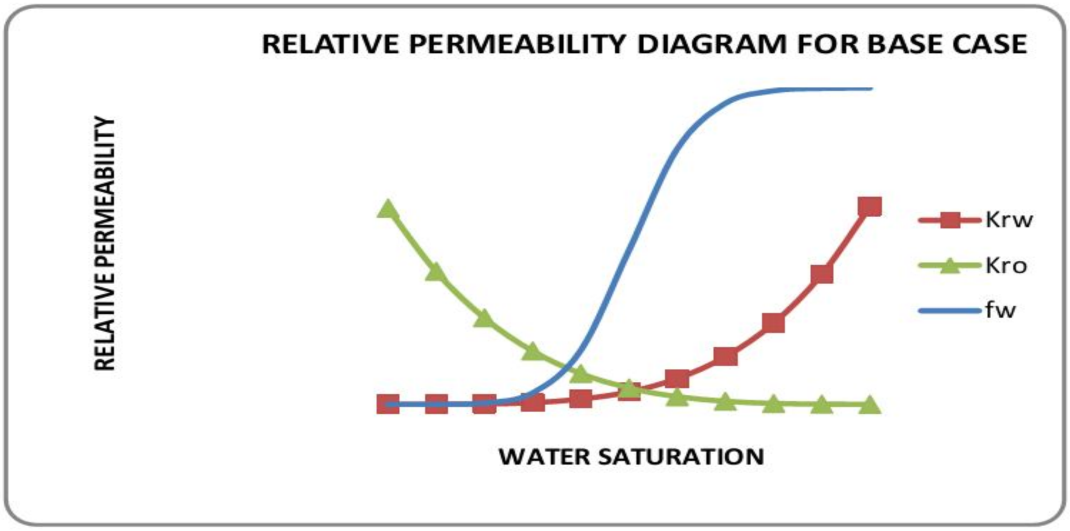

FIGURE 3: RELATIVE PERMEABILITY CURVE DIAGRAM FOR BASE CASE B1

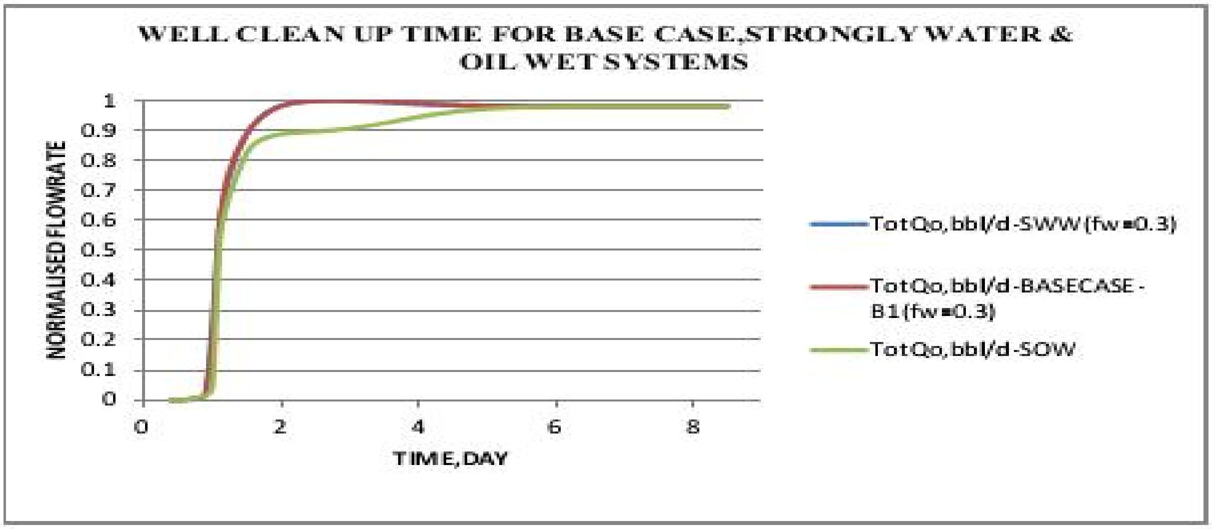

Figure 4: Well Cleanup Time for Base Case, Strongly Water and Oil Wet Systems

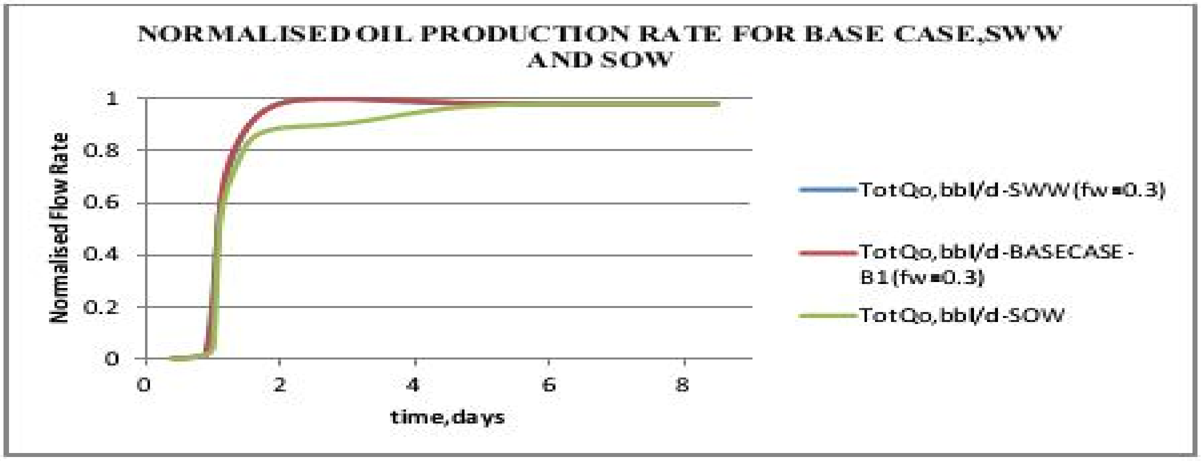

Figure 5: Oil production rate of Base Case, Strongly Water and Oil Wetting Systems at 30% wat
cut

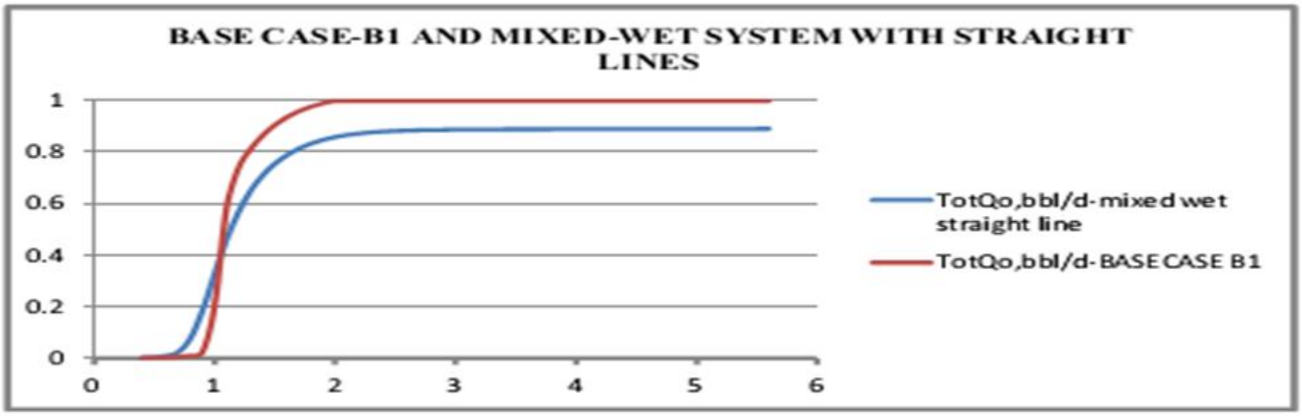

Figure 6: well clean up time for Base Case-B1 and Mixed Wet System with Straight Lines at lower water cut

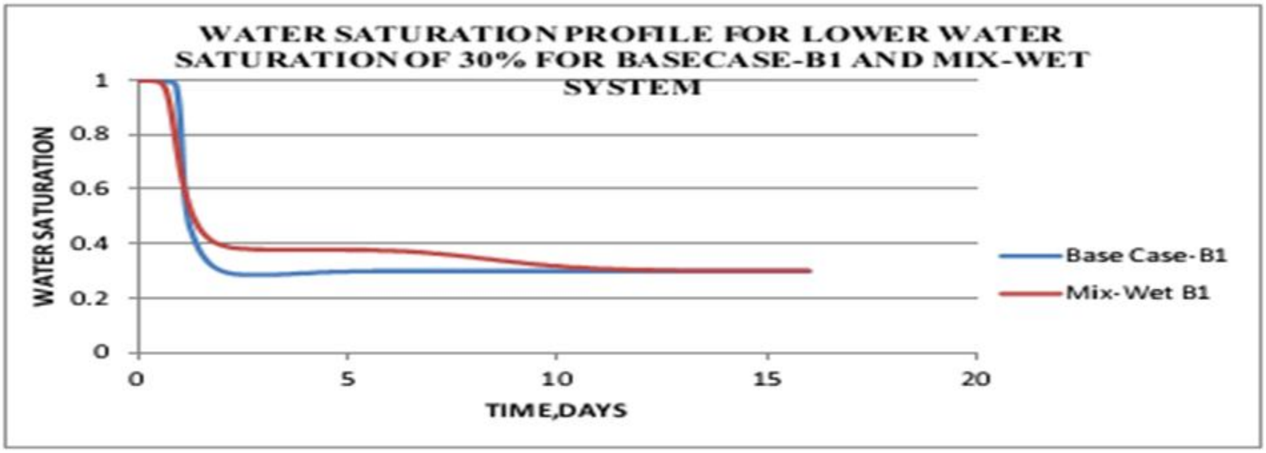

Figure 7: Water Saturation Profile For Lower Water Saturation Of 30% For Base Case-B1 And Mix-Wet System

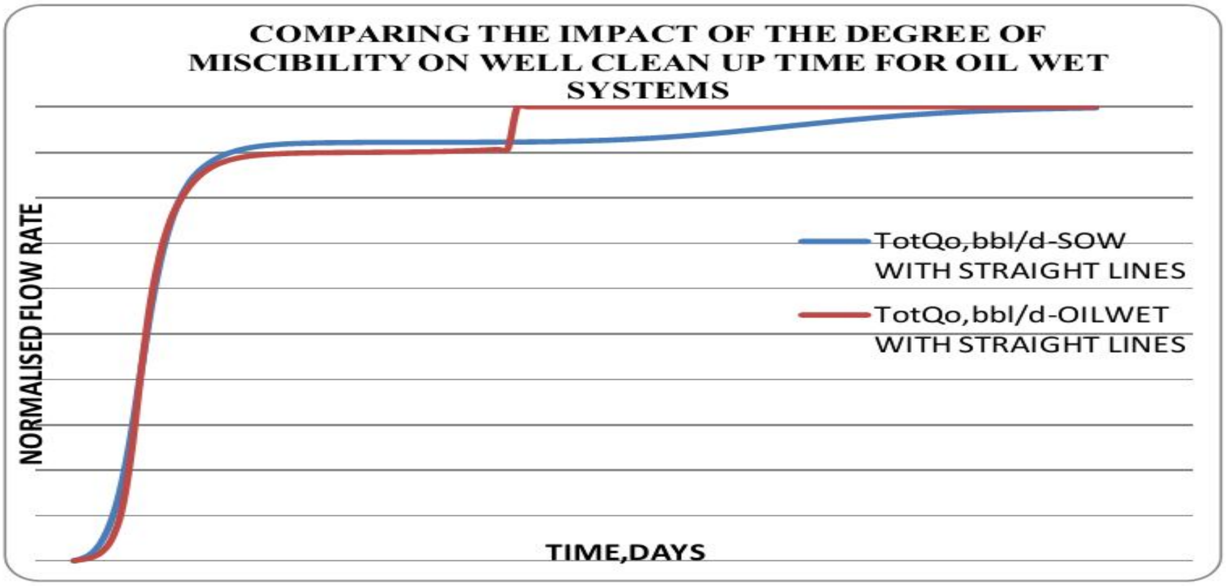

Figure 8: Comparing the impact of the degree of miscibility on well clean up time for oil-wet systems

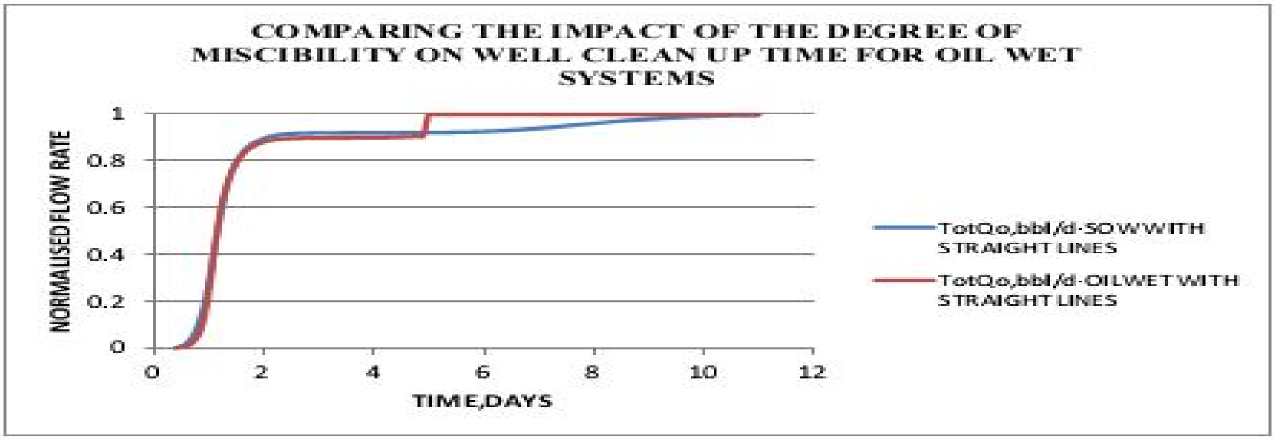

Figure 9: Comparing the impact of the degree of miscibility on well clean up time for oil-wet Systems

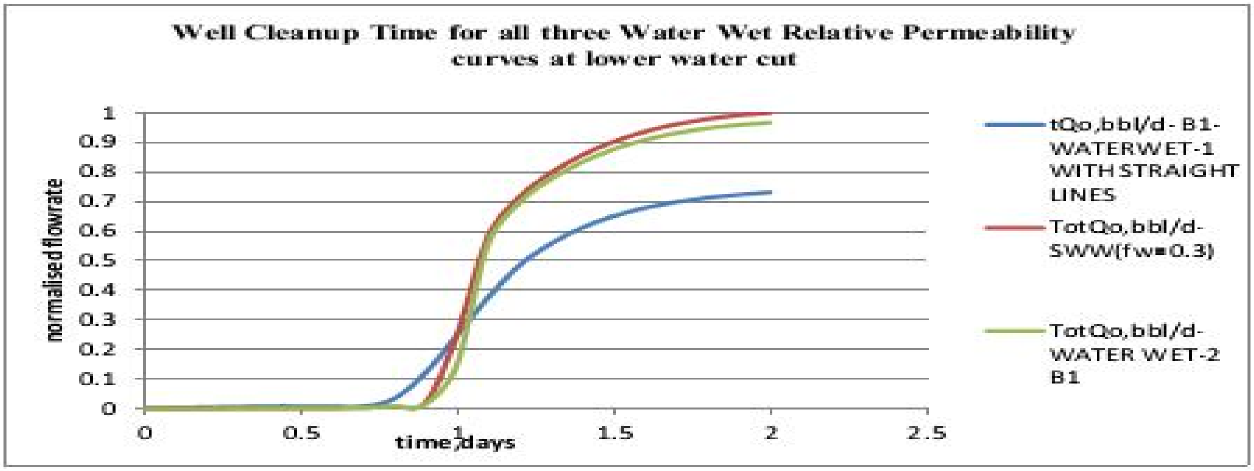

Figure 10: Well Cleanup Time for all three Water Wet Relative Permeability curves at lower water cut

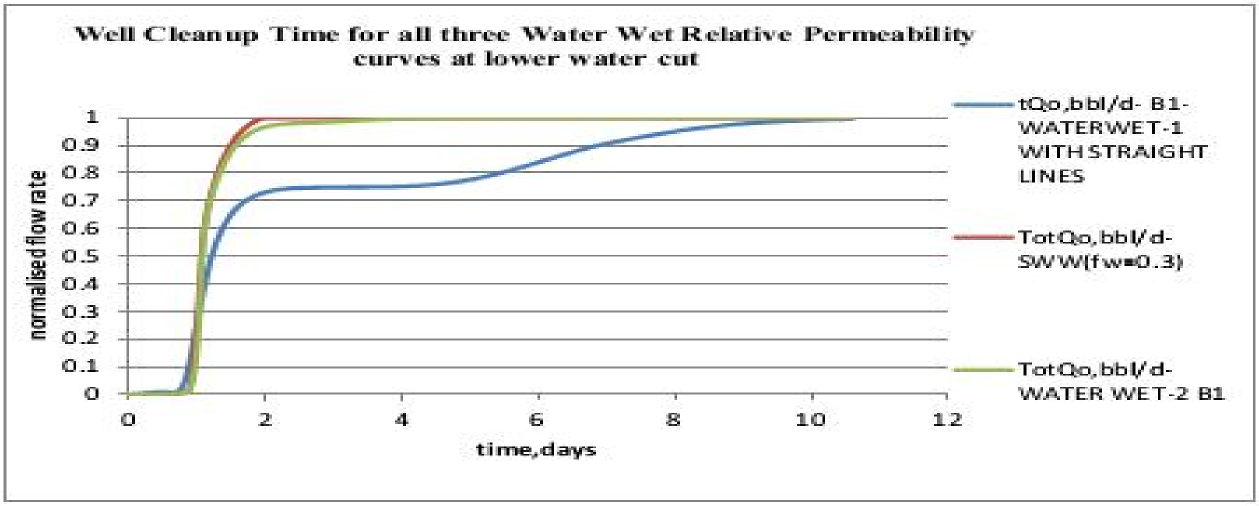

Figure11: Well Cleanup Time for all three Water Wet Relative Permeability curves at lower water cut

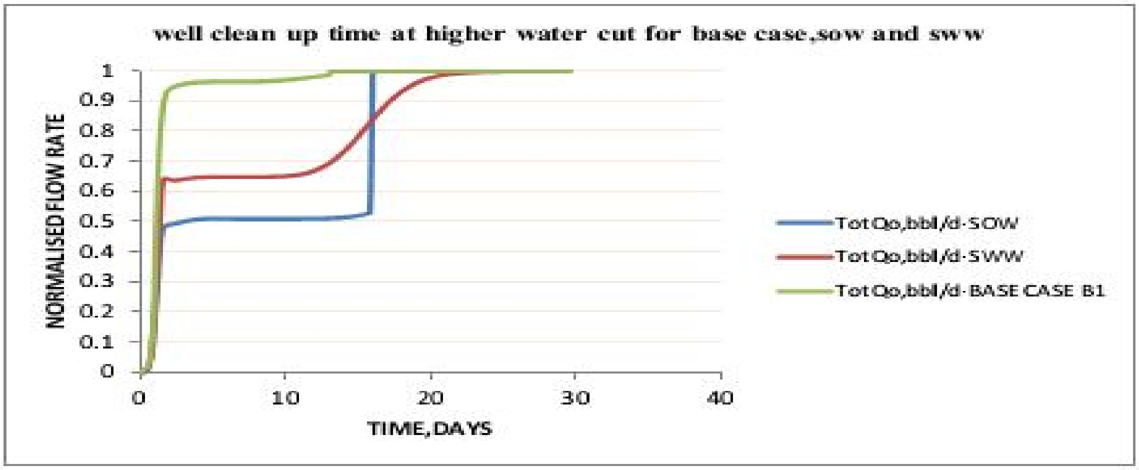

Figure 12: Well Clean-Up time for Base Case, strongly Oil & water wet systems at 95% Water-cut

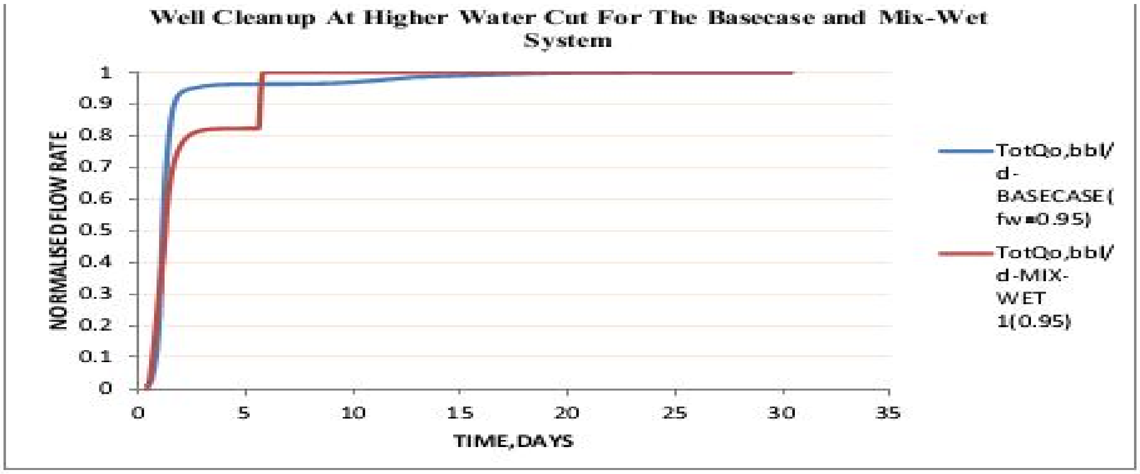

Figure 13: Well Cleanup at Higher Water Cut for the Base case and Mix-Wet System at higher water cuts

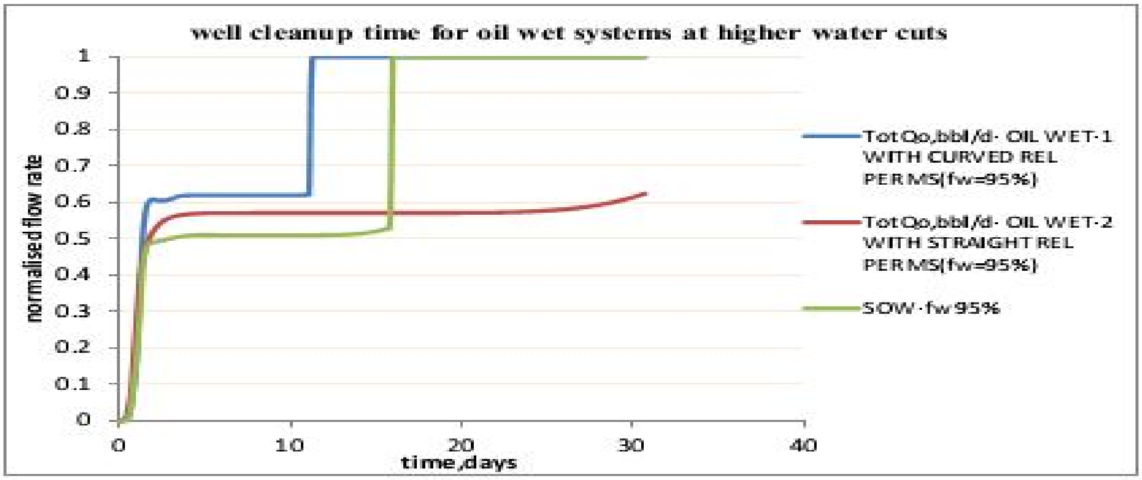

Figure 14: Well Cleanup time for Oil Wet Systems at Higher Water Cuts

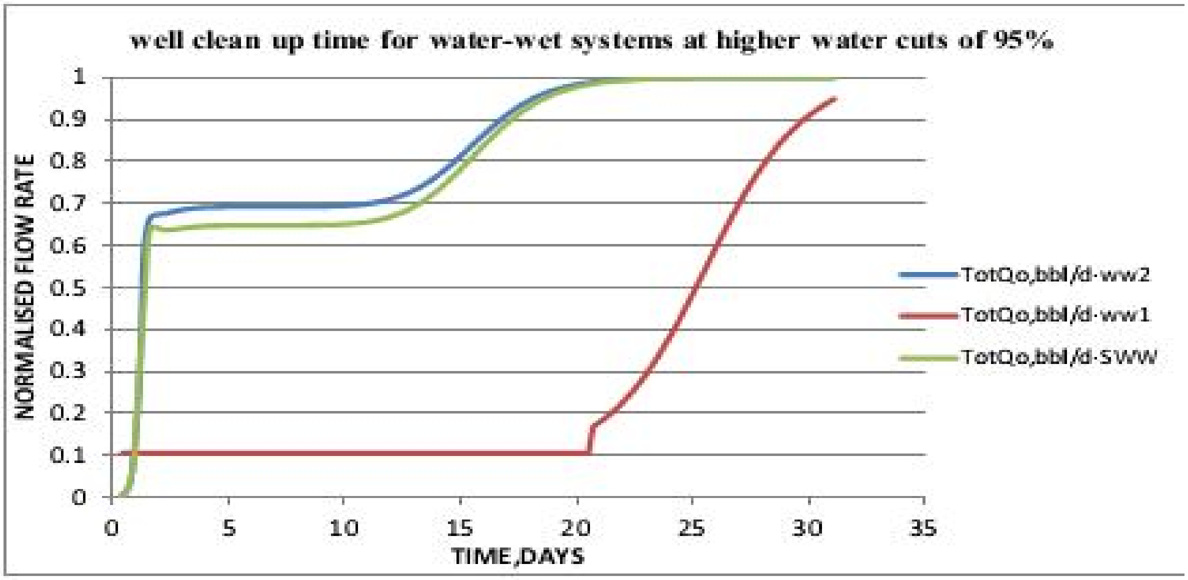

Figure 15: Well clean up time for water-wet systems at higher water cuts of 95%

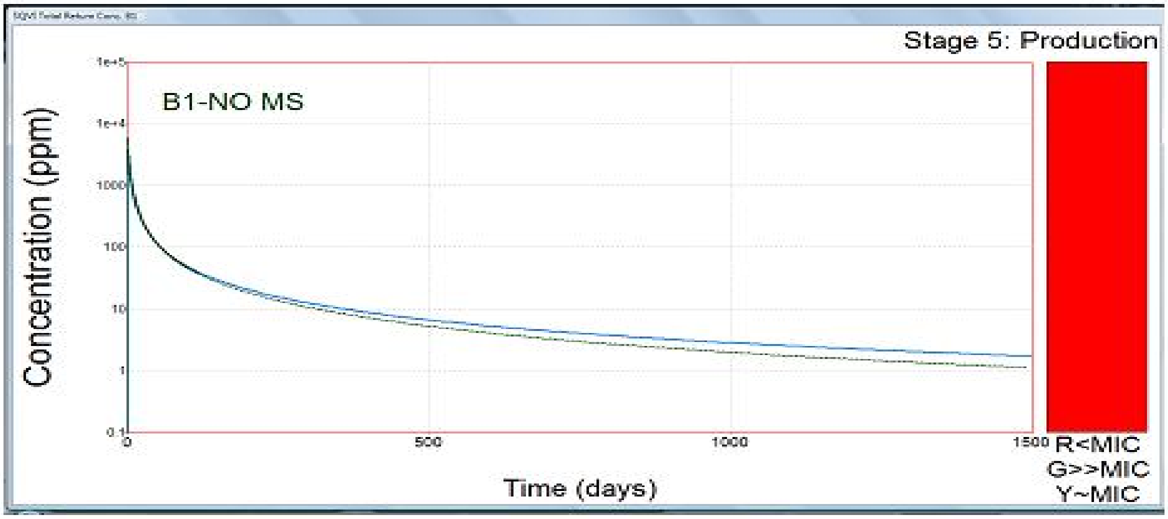

Figure 16: Showing Oil Wet-2 Cases With (B1) And Without Ms (B1-No Ms) Squeeze Life Time