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A Study of Innovative Down-Hole Water Sink Completion Technology to Improve Oil Recovery in Multilayered Reservoir

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Abstract

A reservoir with bottom water drive mechanism has a high tendency to generate water coning effect in their production life. As a result of water coning phenomenon, the well has a low critical safe rates which limit productivity of the reservoir. Consequently, a new innovation for completion design in an oil well with a bottom aquifer drive is needed. The author offers Downhole Water Sink (DWS) system to solve this problem.

DWS is a dual completion design innovation where two tubing string are installed into the well to produce both water and oil simultaneously by different tubing. The main principle of DWS is to create a stable pressure drawdown in oil and water zone so that a stable oil-water contact is formed. DWS application in a multilayered reservoir expected to be able resolve water coning phenomenon thus the recovery factor increase and the well becomes economic to be produced. In this paper, study approach involved by numerical simulation within IMPES methodology (Implicit Pressure Explicit Saturation) and Thomas's algorithm to solve iteration. Completion modeling is creating two wells on the similar coordinate in several layered reservoir aim to produce oil and water separately on tubing on the well.

The percentage of water cut on oil production tubing is 0% while the percentage of water cut on water production tubing is 100%. This thing shows that DWS completion system will give a greater cumulative oil production in a high production rate and the oil is oil free water. It is observed that a successful implementation of DWS in multilayered reservoir is taken place. The well with DWS design configuration for WDP system shows a better performance of oil productivity compare to a conventional well completion design. This result is support by no water production observed at oil production tubing on the surface well level. There are some parameters that affect DWS system application modeling i.e. mobility ratio, vertical and absolute horizontal permeability (kv & kh) also perforation interval.

Down-Hole Water Sink is an appropriate innovation to eliminate water coning and producing oil with high recovery factor. DWS application in a multilayered reservoir with bottom aquifer driving mechanism shows a better performance of oil productivity compare to a conventional well completion design. This result is support by no water production observed at oil production tubing on the surface well level.

Keywords: Water Coning, Down-Hole Water Sink, Oil Recovery

1. Introduction

Economical value of a well depends on its productivity to lift oil to the surface. In economic point of view, Oil Company should produce oil with high liquid rates. Therefore, other production obstacles might be found on the field, water coning is one of the example. This phenomenon is occurred in oil-water well due to high pressure difference near wellbore area where water rates are higher than oil rates and forms a water-bell shape around the perforation zones.

A reservoir with bottom water drive mechanism has a high tendency to generate water coning effect in their production life. As a result of water coning phenomenon, the well has a low critical safe rates which limit productivity of the reservoir. Consequently, a new innovation for completion design in an oil well with a bottom aquifer drive is needed. The author offers Downhole Water Sink (DWS) system to solve this problem.

DWS is a dual completion design innovation where two tubing string are installed into the well to produce both water and oil simultaneously by different tubing. Water scheme are divided into two systems; Water Drainage Production (WDP) is a water production system and Water Drainage Injection (WDI) is the re-injection water system. The main principle of DWS is to create a stable pressure drawdown in oil and water zone so that a stable oil-water contact is formed. DWS system is expected to answer water coning effect and hoped a significant increment of oil productivity and well economics.

In this study, DWS are implemented in multilayer reservoirs with their own aquifer system where other previous study was focusing on single aquifer reservoir system. This case was carried out to further imitate the real situation in a reservoir field where commingle productions are usually found.

2. Basic Theory

Down-hole water sink (DWS) is an effective technology to control water coning phenomenon in an oil well with bottom water drive mechanism. A schematic of a conventional completion and DWS completion are shown in **Fig. 1**. DWS is a dual completion design innovation with packer for partitioning oil and water zone. A short string is set for producing oil while longer string is destined for water production zone. As the result of a decent DWS implementation, water free oil will be produced on water production tubing and oil free water will be produced on oil production tubing. The main principle of DWS is to create a stable pressure drawdown in oil and water zone so that a stable oil-water contact is formed.

For each combination of bottom and top completion rates, pressure distribution is analyzed to describe shape of water (oil) cone. In the model, critical rates (fluid breakthrough) occur when the top of cone taps the well completion. Combinations of all critical rates give a plot of bottom rate vs top rate known as Inflow Performance Window (IPW). An example of such plot is shown in **Fig 2**. The plot comprises a window enveloped by two lines that merge into an unstable contact line at higher rate.

The upper and bottom borderlines of the window represent critical rate for oil and water breakthrough, respectively. The IPW plot identifies three operational modes for DWS wells:

- Segregated inflow, when oil and water separately inflow the top and bottom completion, respectively, and there in no two phase inflow;
- Water coning – with controlled water the top completion but water in flows both the completions;
- Inversed (oil) coning, when oil is produced at the top and bottom completion.

3. Methodology

Study approach of this paper involved by numerical simulation within IMPES methodology (Implicit Pressure Explicit Saturation) and Thomas's algorithm to solve iteration which is built using Eclipse ® and Petrel ®. The model is a sugarbox multilayer reservoir with three different layers that being produced by commingle production. All three reservoir has water-aquifer drive as their driving mechanism.

The first reservoir is 30, 30, 2 (X, Y, Z) where the first layer is oil zone and the second layer is water zone. The perforation interval of oil zone is 2 ft from 5 ft. The second reservoir is 30, 30, 4 (X, Y, Z) where the first to second layer is oil zone and the third to fourth layer is water zone. The perforation interval of oil zone is 2 ft from 10 ft.The third reservoir is 30, 30, 5 (X, Y, Z) where the first to third layer is oil zone and the fourth to fifth layer is water zone. The perforation interval of oil zone is 2 ft from 15 ft. Dynamic multilayer reservoir model is shown in **Fig. 3**.

The study assumed that permeability is isotropy. DWS configuration modeled in Petrel® by creating two wells on the same coordinate that produce oil and water simultaneously. Partition of oil and water zone is done by installing packer in the depth of water-oil contact. A short string (named: Well Production Oil; WPO) is set for producing oil, while longer string (named: Well Production Water; WPW) is destined for water production zone, shown in **Fig. 4**. WDP system is applied in the model that considers the strength and volume of the aquifer. Local grid refinement is also added to the system around wellbore to ease the analysis of water and oil breakthrough.

Optimum rate, defined as oil rate where water coning effect does not occur, is generated by trial and error on Eclipse® reservoir simulation. Each rate will then be plotted in excel to get IPW (Inflow Performance Window) curve and yield the intersection point of oil and water breakthrough which is the limitation of the optimum rate, shown in **Fig. 2.**

The objective of this study is to observe the feasibility of DWS application in commingle multilayer reservoir with bottom aquifer driving mechanism. As the result, the well with DWS design configuration for WDP system shows a better performance of oil productivity compare to a conventional well completion design. This result is support by no water production observed at oil production tubing on the surface well level.

4. Case Study

Initially, reservoir simulation is done by making Inflow Performance Window (IPW) aim to maintain production flow stand in segregated flow. IPW is built by doing trial and error on reservoir simulation considering oil and water rate ratio thus a well with no water and oil coning obtained in the first 5 year of production life.

Optimum production rate defined by picking a segregated zone with no water coning effect which known from the simulation result. The figure below is the result of Inflow Performance Window of the model by doing a trial and error toward top rate (Q_{top}) and bottom rate (Q_{bottom}), **Fig. 5**.

Based on reservoir simulation result during 5 year of production, considering the production rate yield from IPW curve, the oil production rate on WPO string is 120 STB/day and the water production rate on WPW string is 285 STB/day, shown in **Fig. 6.**

Based on **Fig.7**, oil saturation profile of the reservoir is shown in initial condition and after 5 year production.

5. Result and Discussion

With Down-hole Water Sink method, oil is produced with a rate of 120 STB/day and water is produced with a rate of 285 STB/day for five years, shown in **Fig. 6**.

- Field Oil Production Rate (FOPR)
  Production trend of FOPR is shown by orange line. Based on the trend, we gain information that the oil production rate is constant on 120 STB/day for five years, implied no water-coning intervention toward oil production.
- Field Water Production Rate (FWPR)
  Production trend of FWPR is shown by blue line. Based on the trend, we gain information that the water production rate is constant on 285 STB/day for five years, implied no oil-coning intervention toward water production.
- Well Oil Production Rate (WOPR) on Well Production Water (WPW)
  Production trend of WOPR: WPW is shown by yellow line. Based on the trend, we gain information that oil production on water production tubing is constant on 0 STB/day for five years, implied no oil-coning on the well with 285 STB/day of water production rate and 120 STB/day of oil rate.

- Well Water Production Rate (WWPR) on Well Production Oil (WPO)
  Production trend of WWPR: WPO is shown by dark blue line. Based on the trend, we gain information that water production on oil production tubing is constant on 0 STB/day for five years, implied no water-coning on the well with 285 STB/day of water production rate and 120 STB/day of oil rate.
- Field Oil Production Total (FOPT)
  Production trend of FOPT is shown by green line. Based on the trend, we gain information that oil production total for five years increase constantly at 222,116 STB and recovery factor at 13% (OOIP = 1,687,606 bbl).

From the oil-saturation-profile figure, shown in **Fig. 7,** a stable oil-water contact seen on reservoir 1, 2 and 3. This result is support by on water zone against the oil zone.

6. Conclusion

Reservoir simulation result of water-coning handling with Down-hole Water Sink yield 120 STB/day of oil production rate and 285 STB/day of water production rate. Furthermore, this study result with no water production in oil production tubing and no oil production in water production tubing. Based on the result, this study is succeed for handling the water coning phenomenon on multilayer reservoir. after doing a trial and error on reservoir simulation, limitation of minimum thickness that applicable for DWS method is 5 ft.

7. Recommendation

The limitation of oil zone and water zone netpay which is applicable for Down-hole Water Sink method for reservoir 1, 2 and 3 is 5 ft for the least. This yield after a trial and error of reservoir simulation has done.

8. References

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List of Figures

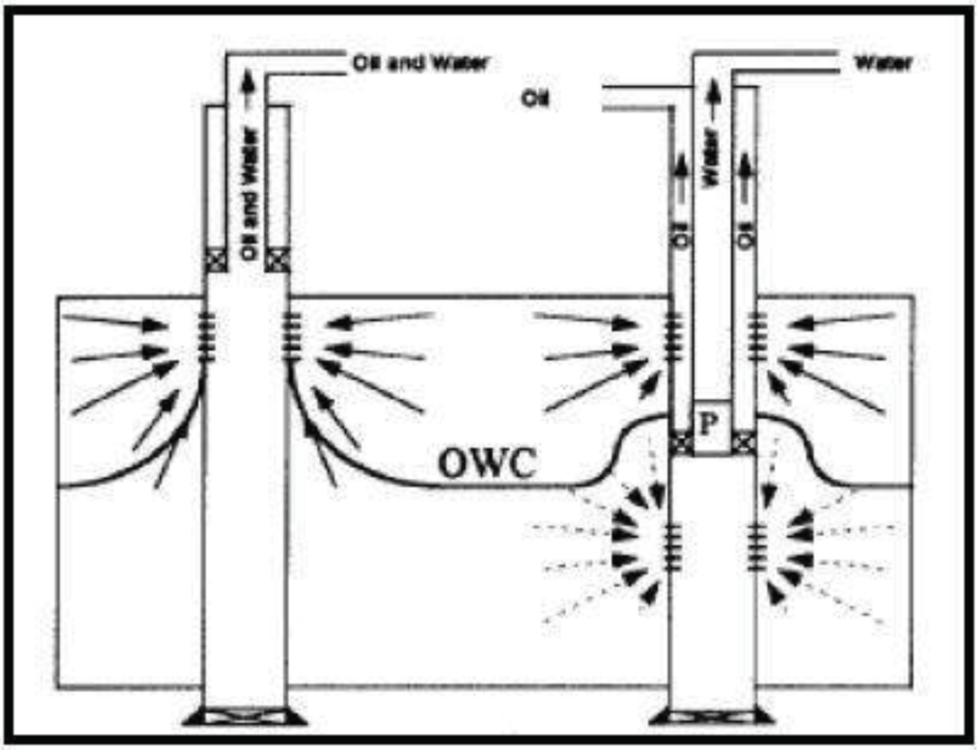


Figure 1. Comparison between Conventional and DWS Completion

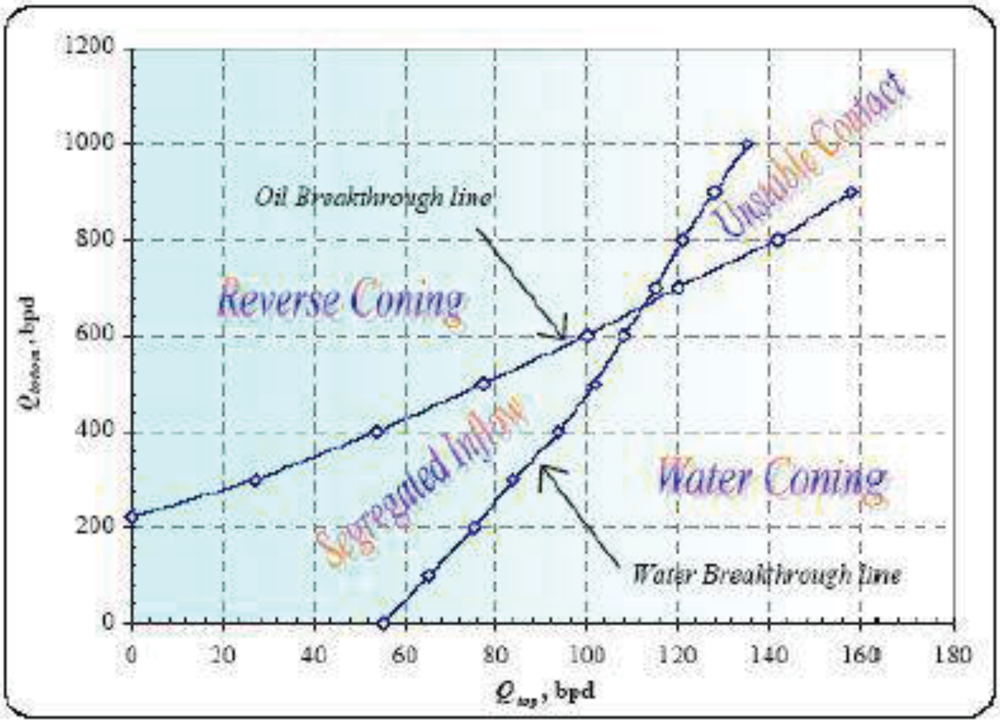


Figure 2. IPW Curve Region

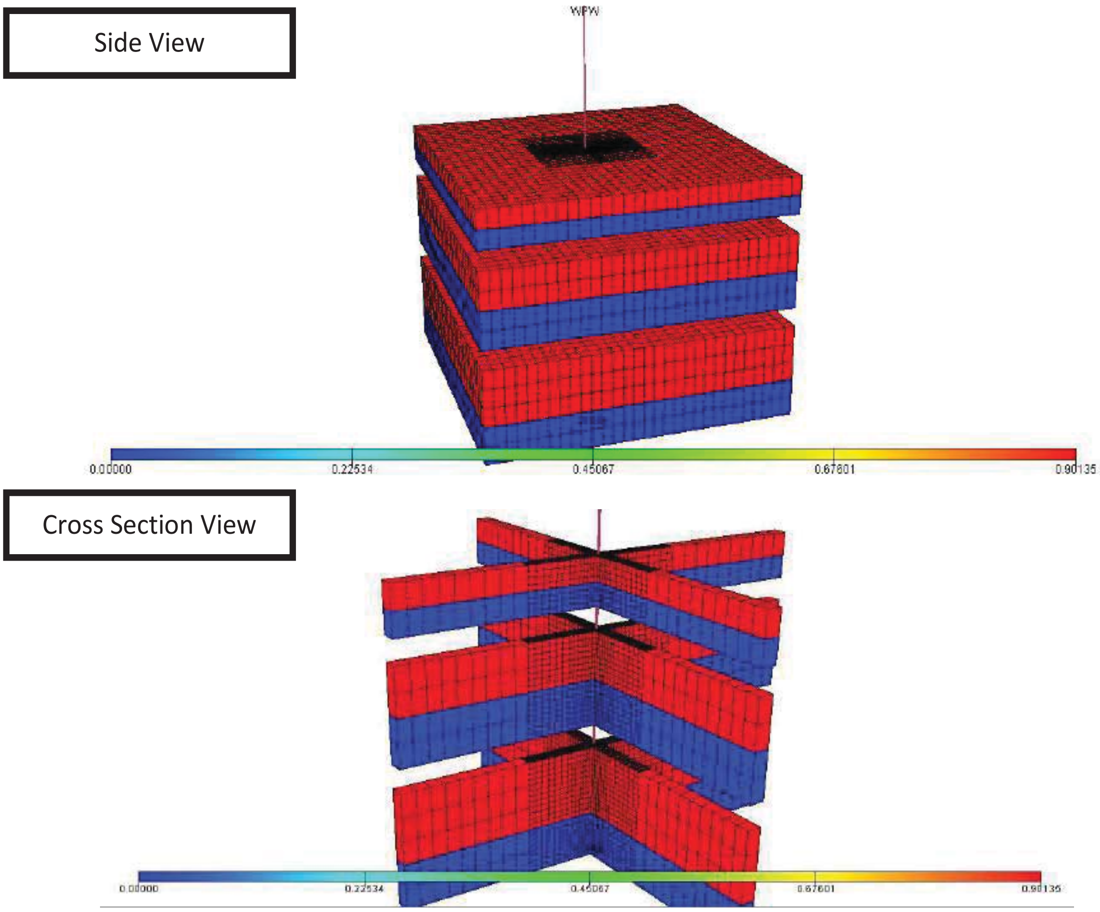
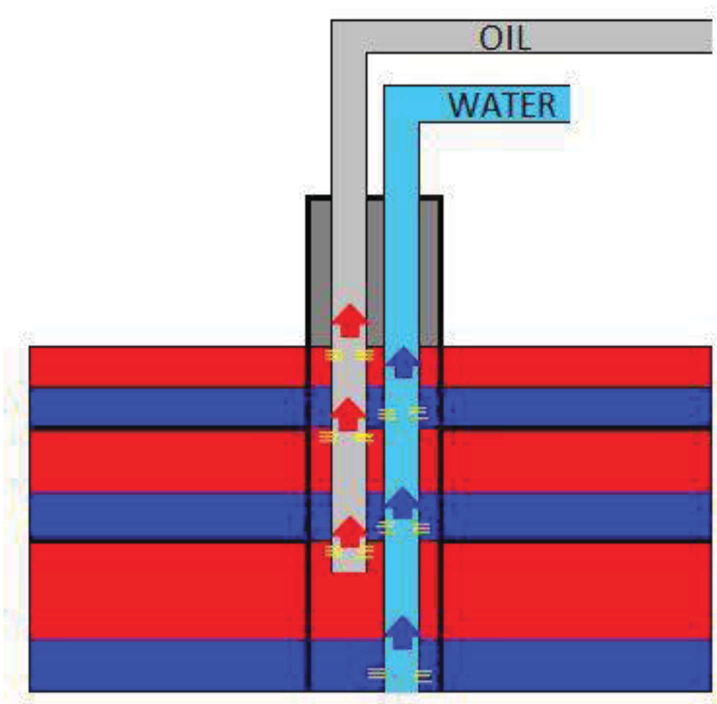


Figure 3. Dynamic Multilayer Reservoir Model



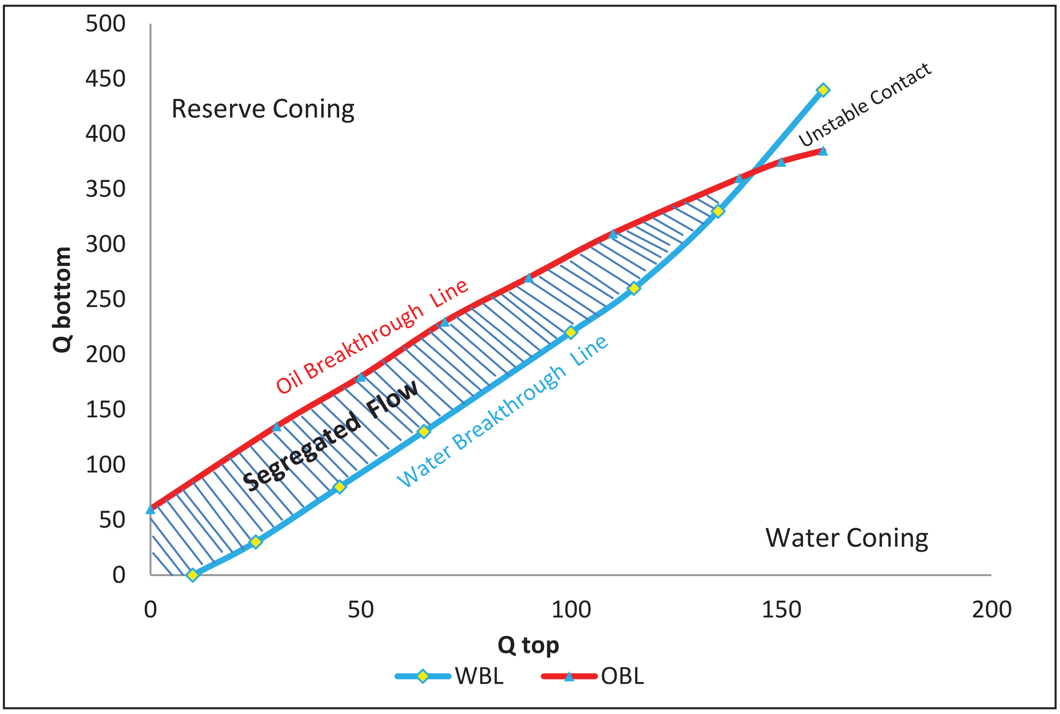


Figure 5. Inflow Performance Window Curve

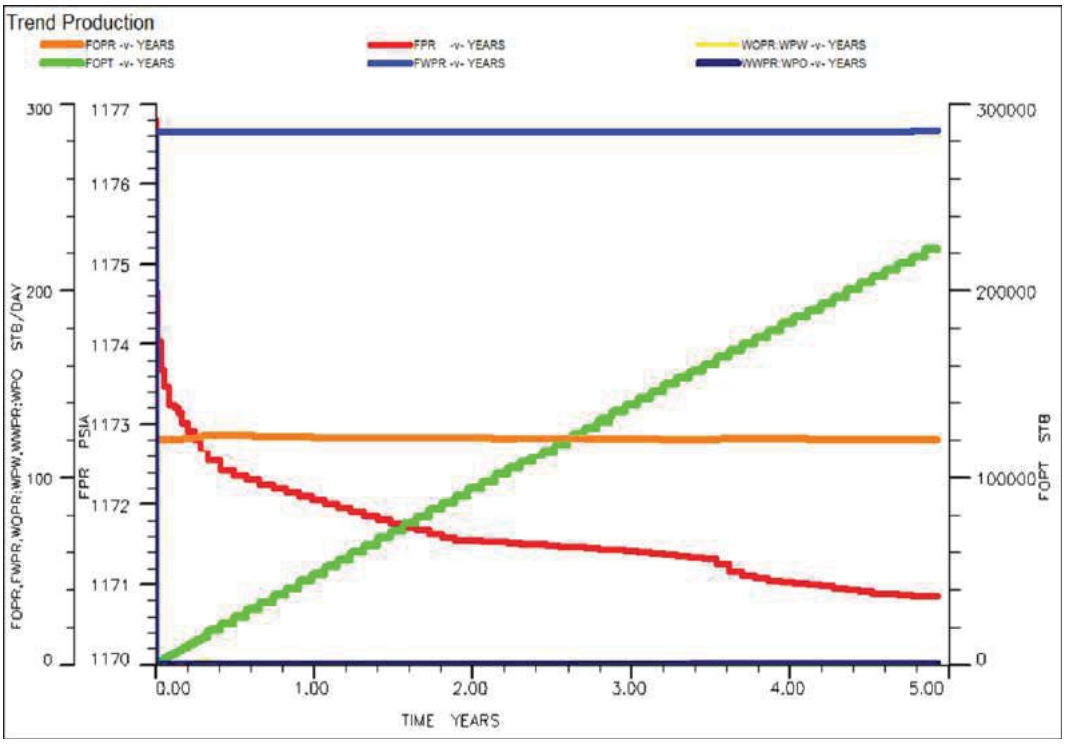


Figure 6. Well Production Profile

: Field Oil Production Rate (FOPR)
: Field Water Production Rate (FWPR)
: Well Oil Production rate (WOPR) at Well Production Water (WPW)
: Well Water Production Rate (WWPR) at Well Production Oil (WPO)
: Field Oil Production Total (FOPT)
: Field Pressure (FPR)

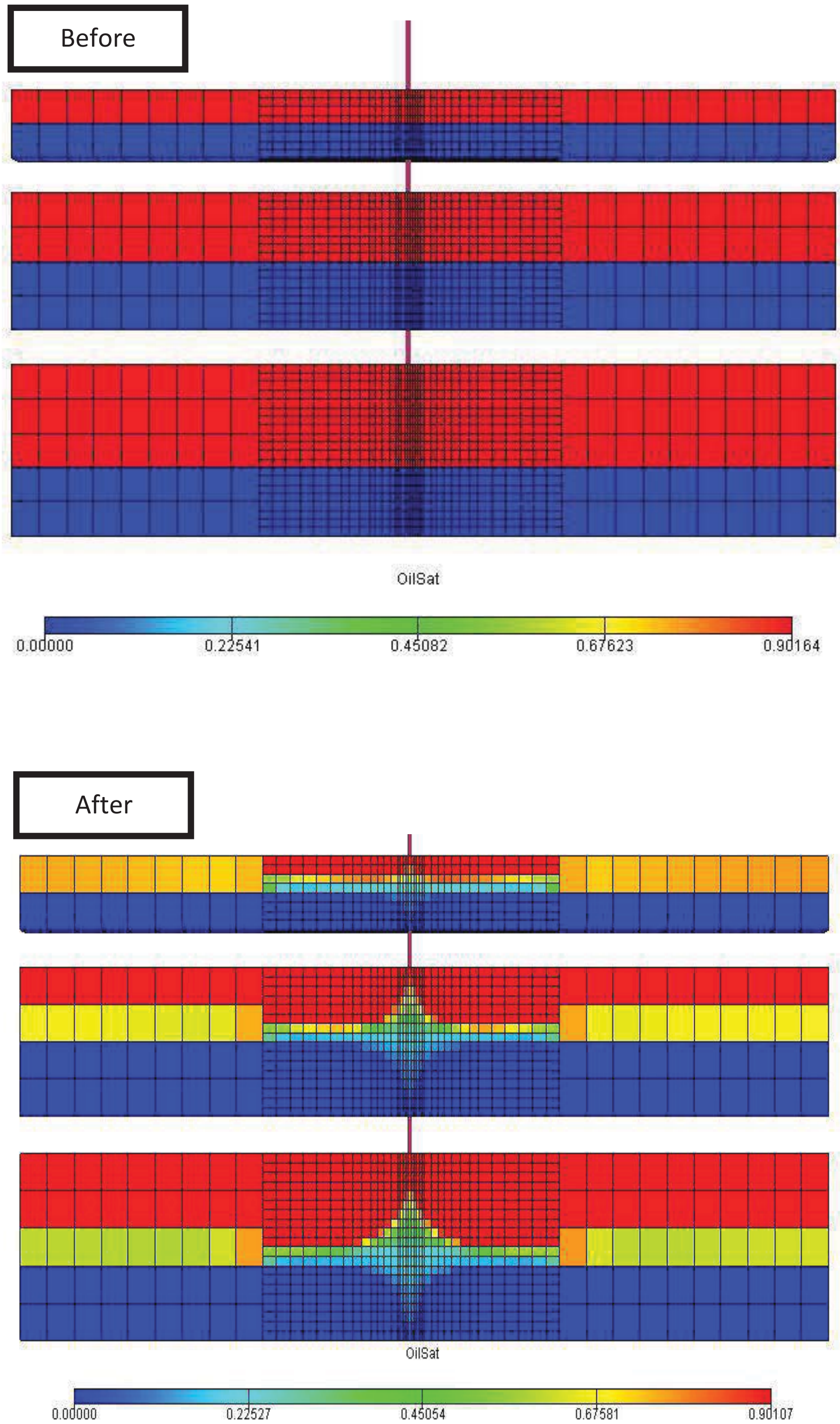


Figure 7. Oil Saturation Profile

Appendix A. Reservoir Data Properties

INPUT DATA RES 1	Value	Unit
Reservoir pressure	1161.22	psi
Thickness of oil/gas column	5	ft
Thickness of water column	5	ft
Depth of OWC	2793	ft
Length of oil production perforation	3.3	ft
Length of water production perforation	6	ft
Horizontal permeability in oil column	311	mD
Vertical permeability in oil/gas column	31	mD
Horizontal permeability in water column	311	mD
Vertical permeability in water column	31	mD
Water density at temperature	64.79	Ib/ft^3
Oil density at temperature	49.1	Ib/ft^3
Oil viscosity at temperature	1.03	cP
Water viscosity at temperature	0.57	cP
Reservoir temperature	128	^{o}F
Porosity in oil column	0.27	Fraction
Porosity in water column	0.3	Fraction
Oil formation volume factor	1.1413	Rb/stb
Water formation volume factor	1.011	Rb/stb
Oil gravity	36	^{o}API
Completion diameter/hole size	7	inches
Re	328	ft

AQUIFER RES 1	Value	Unit
Datum depth	2820	ft
Initial aquifer pressure at the datum depth	Defaulted	psi
Permeability of the aquifer	311	mD
Porosity of the aquifer	0.3	Fraction
Total (rock + water) compressibility of the	3.4E-5	1/psi
Aquifer flux	0.00002	stb/d/ft^2

INPUT DATA RES 2	Value	Unit
Reservoir pressure	1170	psi
Thickness of oil/gas column	10	ft
Thickness of water column	10	ft
Depth of OWC	2813	ft
Length of oil production perforation	3.3	ft
Length of water production perforation	6	ft
Horizontal permeability in oil column	290	mD
Vertical permeability in oil/gas column	29	mD
Horizontal permeability in water column	290	mD
Vertical permeability in water column	29	mD
Water density at temperature	64.79	lb/ft^3
Oil density at temperature	49.1	lb/ft^3
Oil viscosity at temperature	1.03	cP
Water viscosity at temperature	0.57	cP
Reservoir temperature	128	^{o}F
Porosity in oil column	0.20	Fraction
Porosity in water column	0.3	Fraction
Oil formation volume factor	1.2281	Rb/stb
Water formation volume factor	1.021	Rb/stb
Oil gravity	34	^{o}API
Completion diameter/hole size	7	inches
R_e	328	ft

AQUIFER RES 2	Value	Unit
Datum depth	2813	ft
Initial aquifer pressure at the datum depth	Defaulted	psi
Permeability of the aquifer	290	mD
Porosity of the aquifer	0.3	Fraction
Total (rock + water) compressibility of the	3.6E-5	1/psi
Aquifer flux	0.00002	stb/d/ft^2

INPUT DATA RES 3	Value	Unit
Reservoir pressure	1183	psi
Thickness of oil/gas column	15	ft
Thickness of water column	10	ft
Depth of OWC	2843	ft
Length of oil production perforation	3.3	ft
Length of water production perforation	6	ft
Horizontal permeability in oil column	187	mD
Vertical permeability in oil/gas column	18	mD
Horizontal permeability in water column	187	mD
Vertical permeability in water column	31	mD
Water density at temperature	64.79	Ib/ft^3
Oil density at temperature	49.1	Ib/ft^3
Oil viscosity at temperature	1.03	cP
Water viscosity at temperature	0.42	cP
Reservoir temperature	161	^{o}F
Porosity in oil column	0.24	Fraction
Porosity in water column	0.3	Fraction
Oil formation volume factor	1.1413	Rb/stb
Water formation volume factor	1.021	Rb/stb
Oil gravity	34	^{o}API
Completion diameter/hole size	7	inches
Re	328	ft

AQUIFER RES 3	Value	Unit
Datum depth	2843	ft
Initial aquifer pressure at the datum depth	Defaulted	psi
Permeability of the aquifer	187	mD
Porosity of the aquifer	0.24	Fraction
Total (rock + water) compressibility of the	3.6E-5	1/psi
Aquifer flux	0.00002	stb/d/ft^2