PERC Petroleum Research Center

THE UNIVERSITY OF UTAH

SPE 99715
Modeling of Multilateral and Maximum Reservoir Contact Wells in Heterogeneous Porous Media

Yi-Kun Yang and Milind D. Deo

Abstract

1. A novel line-well model is proposed for multilateral and maximum contact wells.

2. The proposed model is suitable for highly heterogeneous domain.

3. Verification of the line-well model is done through grid refinement study and comparison with Peaceman's model.

4. The line-well model is implemented using the mixed finite-volume method in this paper but it can also be implemented in finite difference method.

5. Complicated domains are simulated to demonstrate its suitability for embedding wells in systems of complex geometry.

1. Numerical method: Mixed-finite-volume

Flux is approximated in RT0 space.

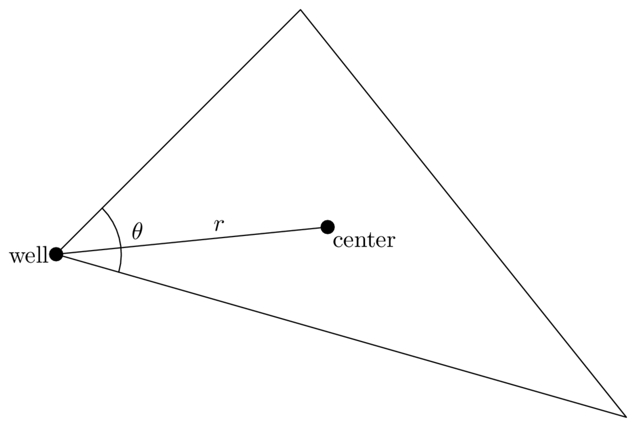
$$\underline{v}_i = (a_i + c_i x, b_i + c_i y).$$

Finite-volume formulation:

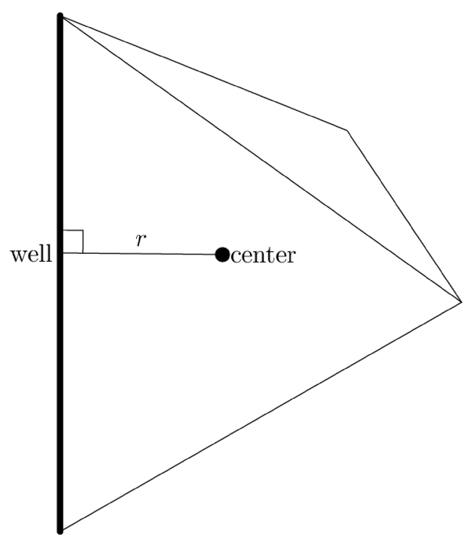
$$\sum_{i=0}^{2} \frac{k_r}{B\mu} f_i\, l_i + \frac{|T|}{\Delta t}\left[\left(\frac{\phi S}{B}\right)^{n+1} - \left(\frac{\phi S}{B}\right)^{n}\right] + |T|\, q = 0$$

2. Line-well model

2D



Well in a 3D tetrahedron



Flow rate:

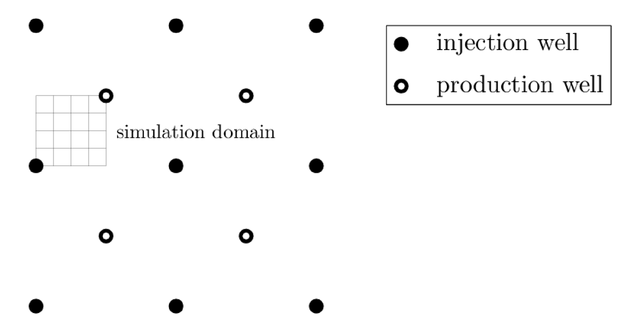
$$q_l = \frac{k_{rl}}{B_l \mu_l} \frac{\theta k}{\ln(r/r_w)} (P_l - P_w)$$

Production Index:

$$\mathrm{PI} = \frac{\theta h k}{\ln(r/r_w)}.$$

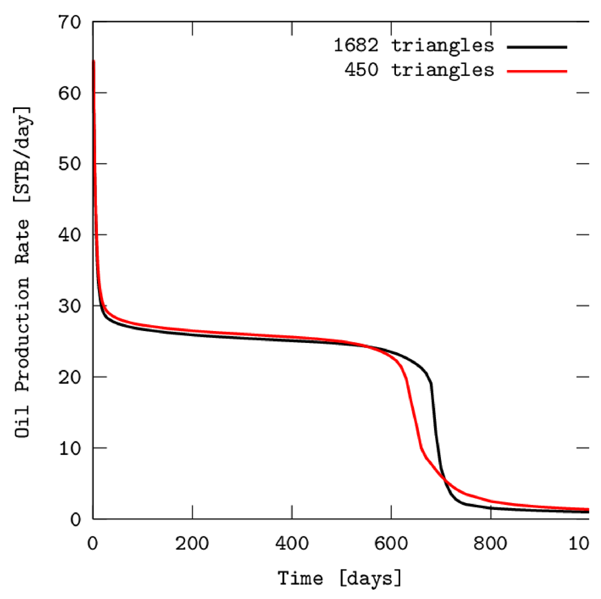
3. Model validation

Quarter of a five-spot production-injection pattern

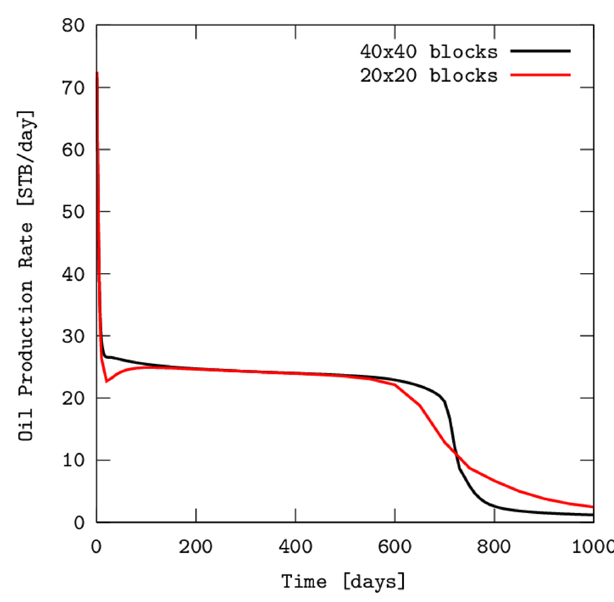


3.1 Validation through grid refinement study

Oil production rates of the line-well model at two grid resolutions using the mixed finite-volume formulation. Differences in production rate due to changes in grid resolution are in acceptable range.

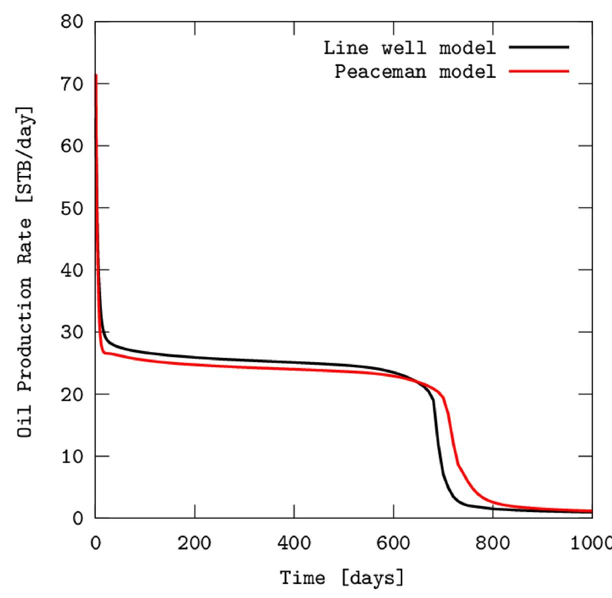


The grid refinement study is performed using the Peaceman's model and the finite difference method (Eclipse™). Oil rates at two grid resultions are shown. Similar behavior is observed in the finite difference method here as in the line-well model with the mixed finite-volume method.



3.2 Validation with the Peaceman's model

The oil production rates from the two comparable finer grids are reploted in the following graph. There is very good agreement between the results from the two well models.



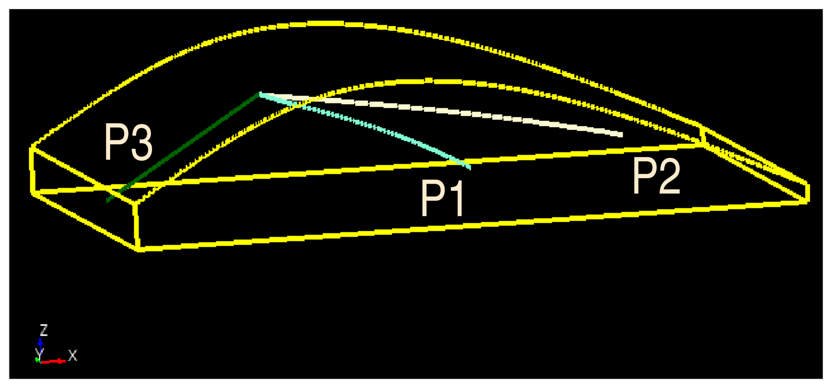
4. Complex geometry and well configuration examples

4.1 Multilateral well

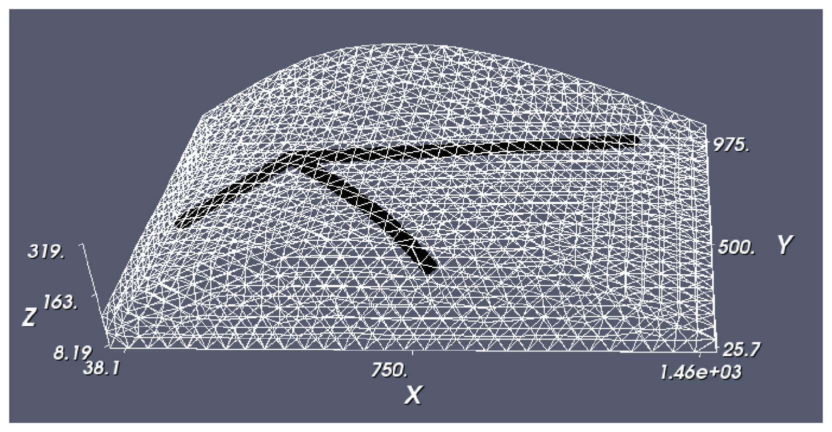
A dome-shaped domain is used to demonstrate the applicability of the line-well model in multilateral configuration. The domain is approximately 1500 feet long, 1000 feet wide and 375 feet in height.

Three production laterals are placed as shown in the following figures. The bottom of the domain is an aquifer at constant boundary pressure.

The dome-shaped domain and the three laterals.

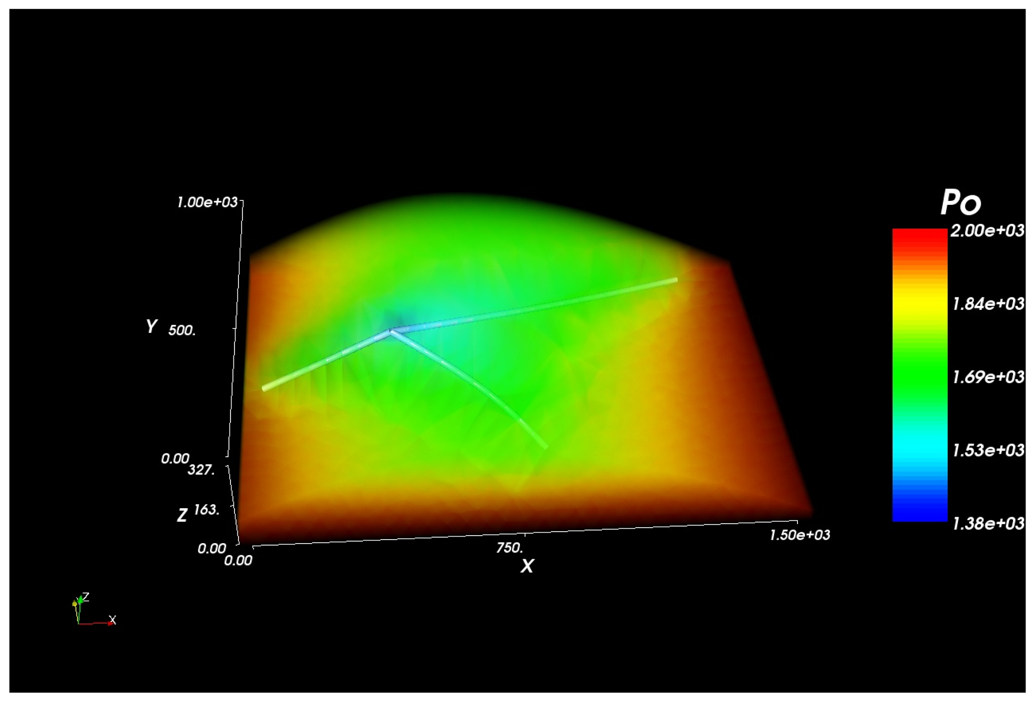


The tetrahedral mesh.

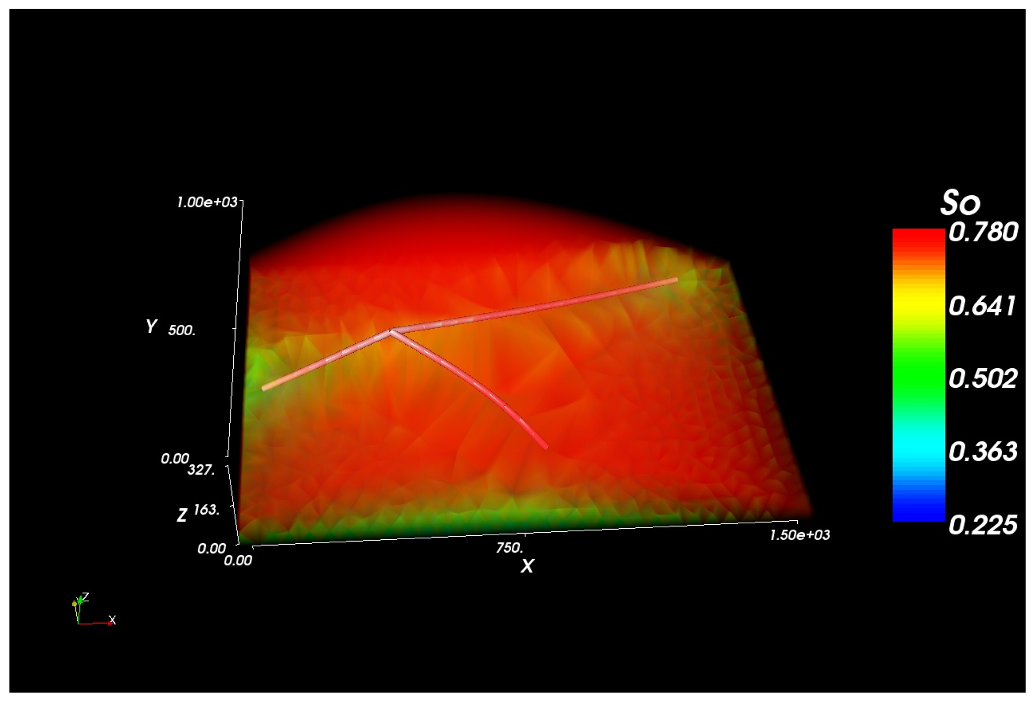


The lowest oil pressure is at the junction of the three laterals and the highest oil pressure is at the aquifer boundary. Oil saturation distrubutions at different times indicate the migration of water from the aquifer toward the three production laterals.

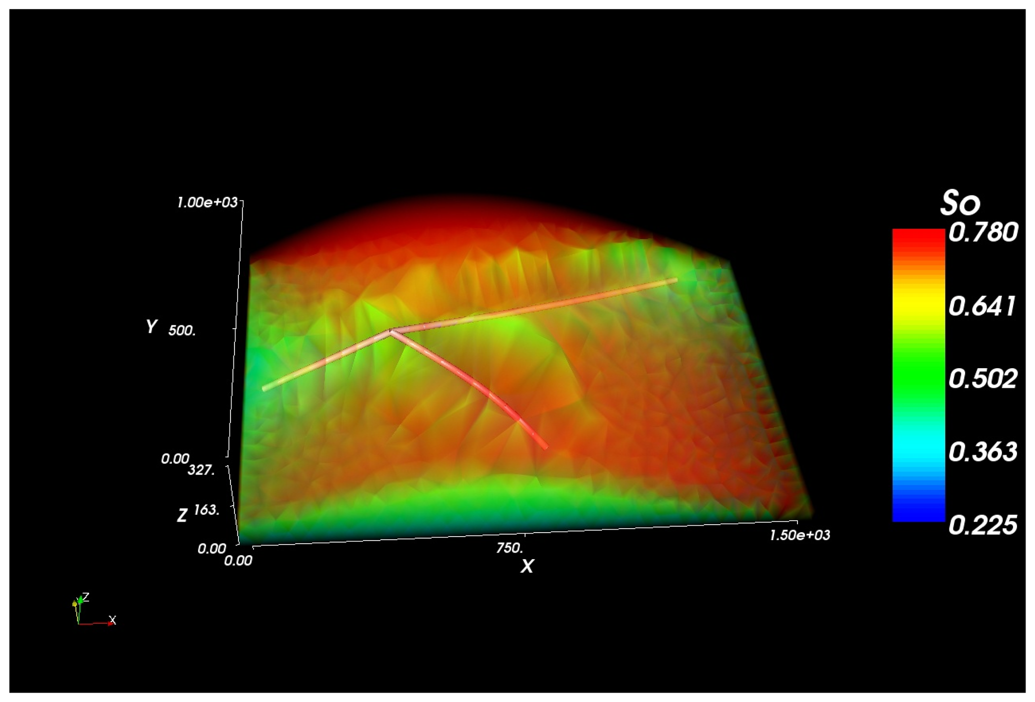
Oil pressure distribution at 5000 days.



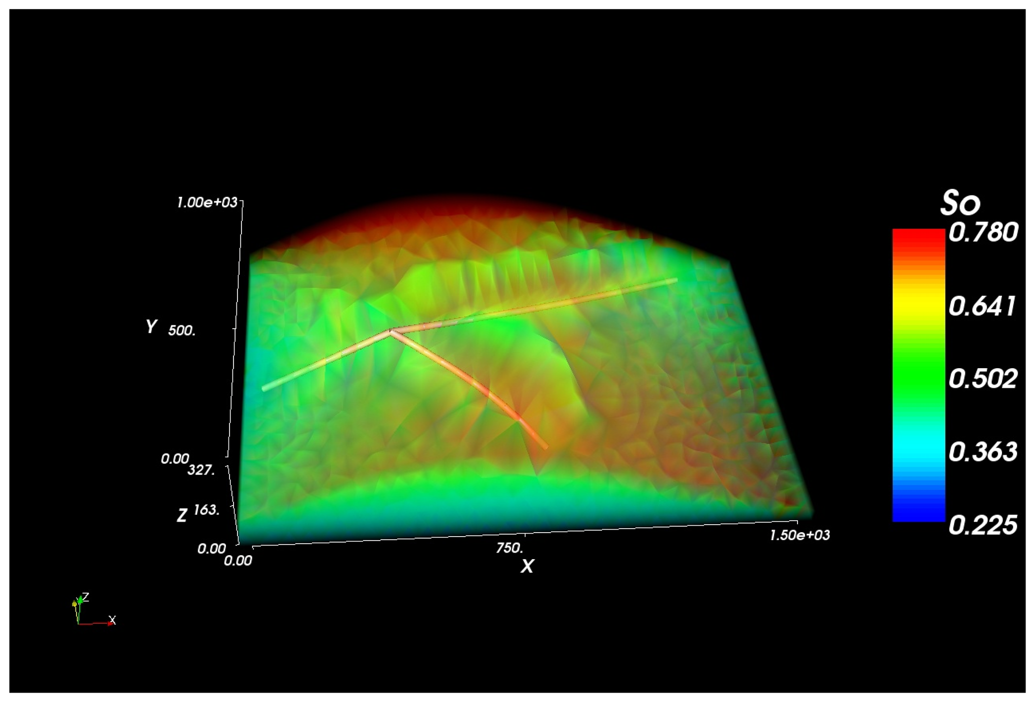
Oil saturation at 500 days.



Oil saturation at 2000 days.

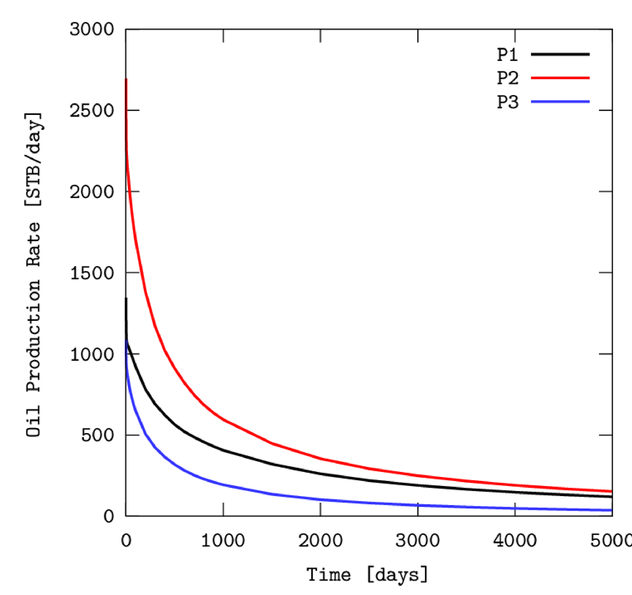


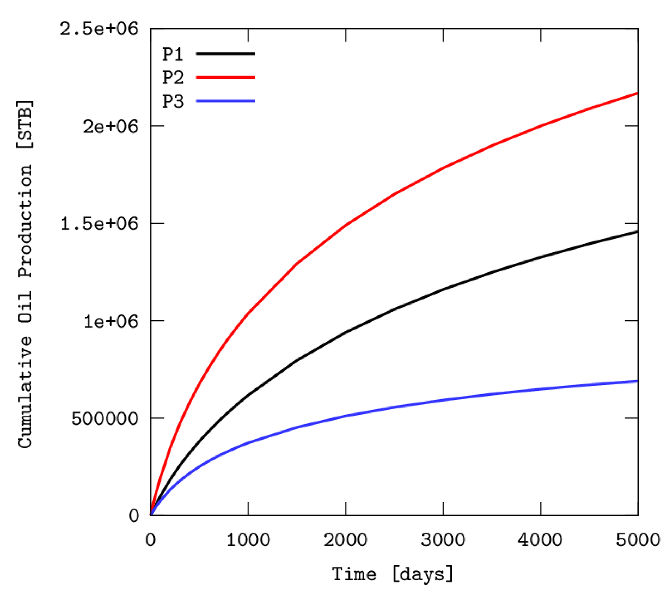
Oil saturation at 5000 days.



Oil rates and cumulative oil productions

P1 is the one in the front, P2 is the one on the right and P3 is on the left.





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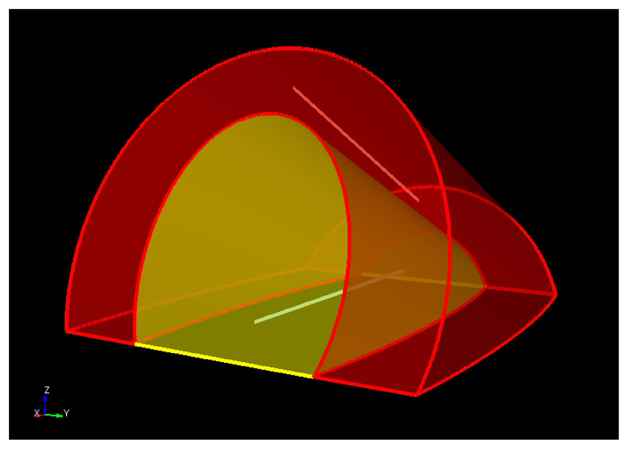
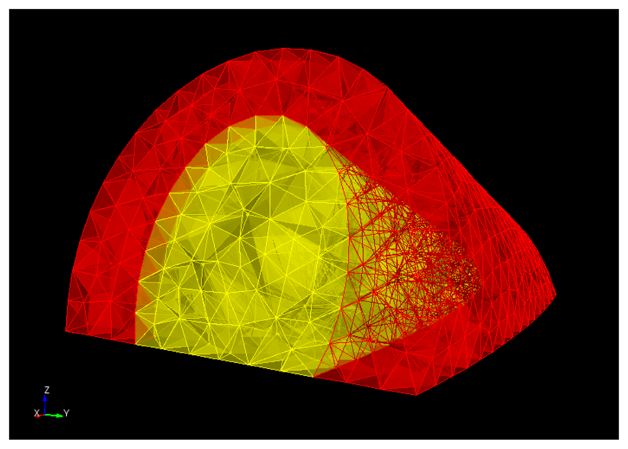
4.2 Complex geometry: Thermal simulation

The domain and the placement of two wells.

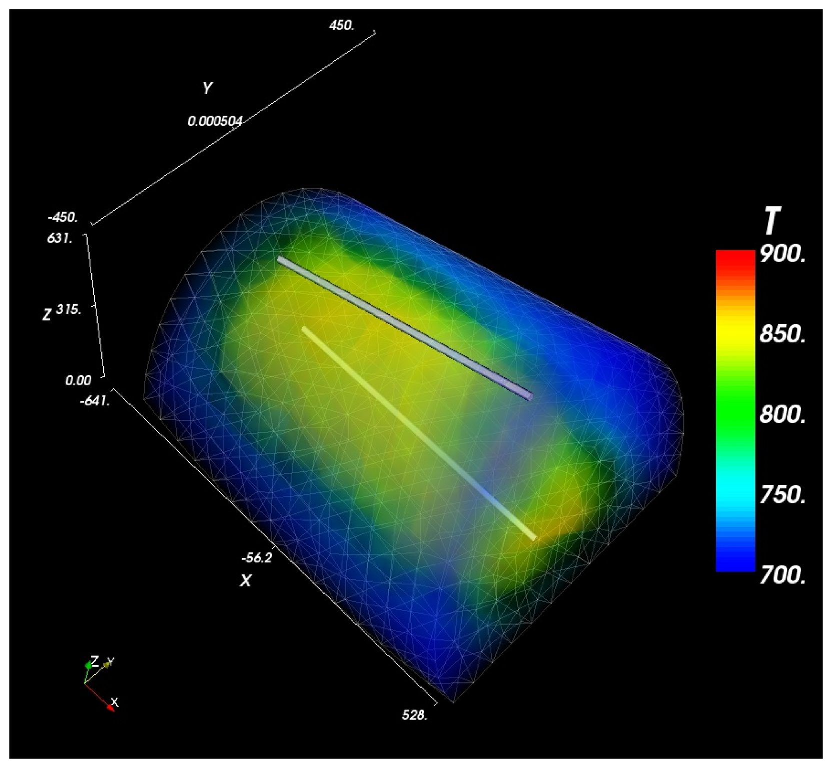


The tetrahedral mesh.

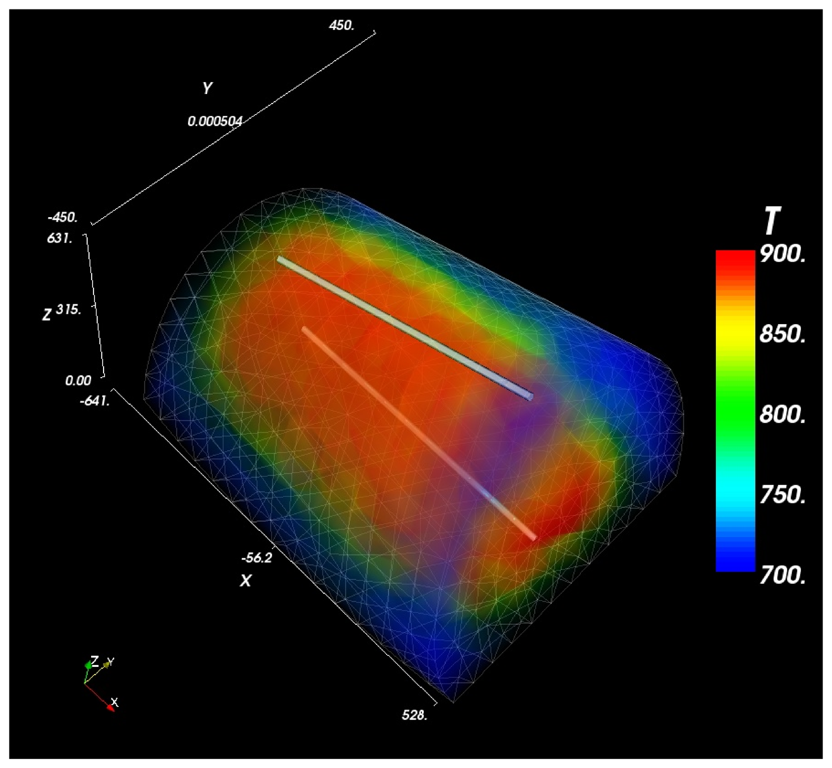


There are two cores; the inner core is at a permeability of 10 md, and the outer core has 100 md permeability.
An oil-production well is placed at the top and a hot-water-injection well is placed at the bottom.

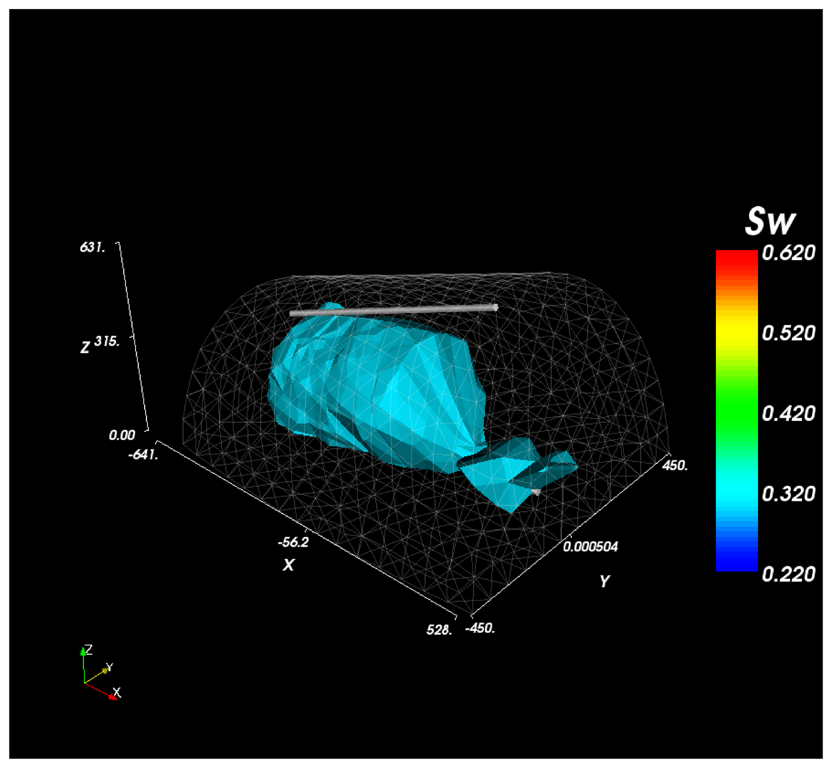
Temp. distribution at 2000 days with water injection temp. = 800 R.

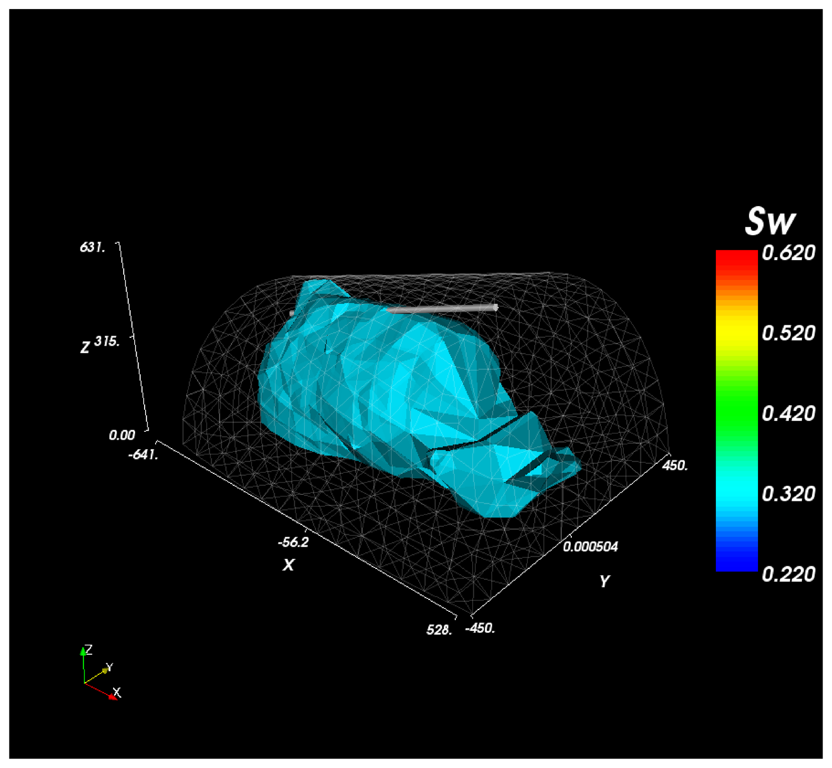


Temp. distribution at 2000 days with water injection temp. = 900 R.

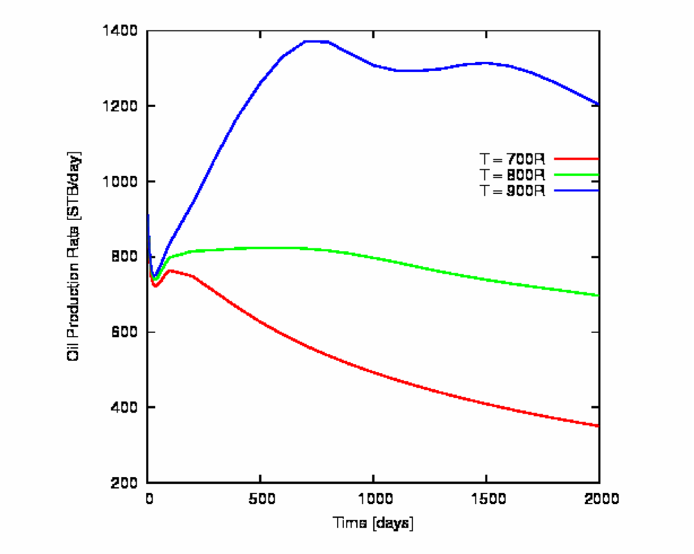


Water saturation contour at Sw=0.3, time=1000 days and water injection temperatures are 800 R and 900 R.
Quicker water migration is observed at higher water injection temperature.





Oil production rates increase as injection temperature increases.



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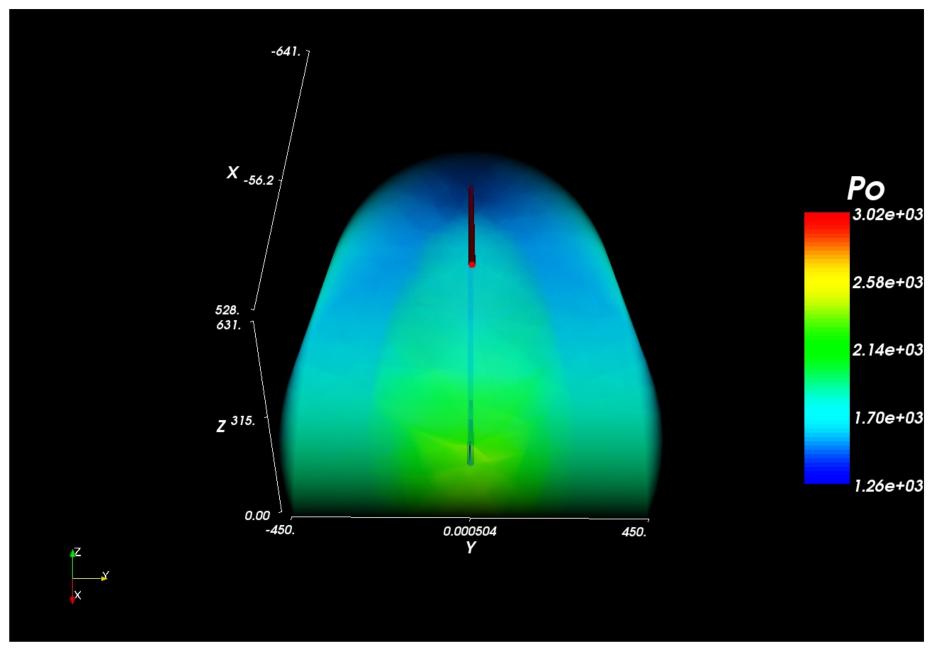
4.3 Complex geometry: Black oil simulation:

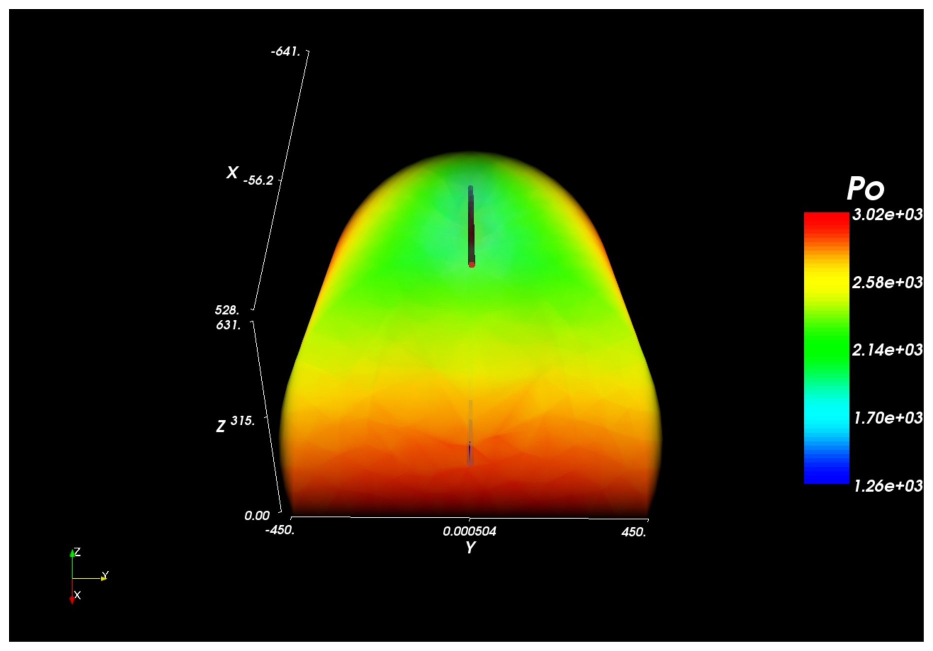
Two black oil simulations of the folded domain with different permeability distributions are studied to demonstrate the usability of the line-well model and the mixed-finite-volume formulation.

Case I
Inner layer: k = 10 md
Outer layer: k = 100 md

Case II
Inner layer: k = 100 md
Outer layer: k = 10 md

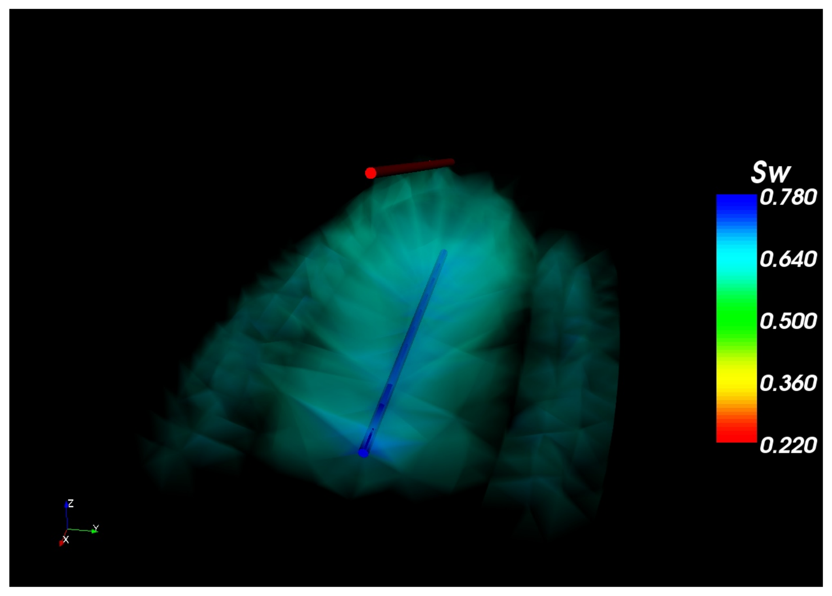
Oil pressure distribution at 2000 days.

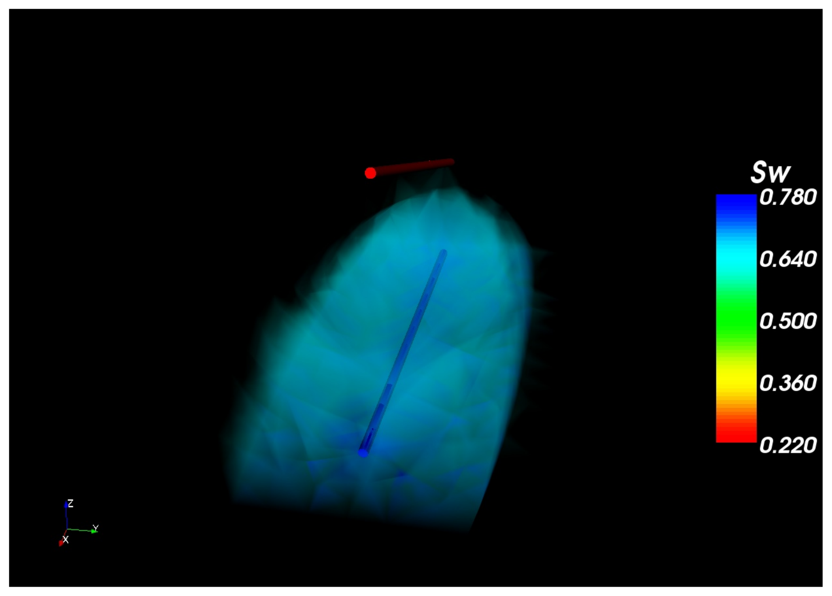




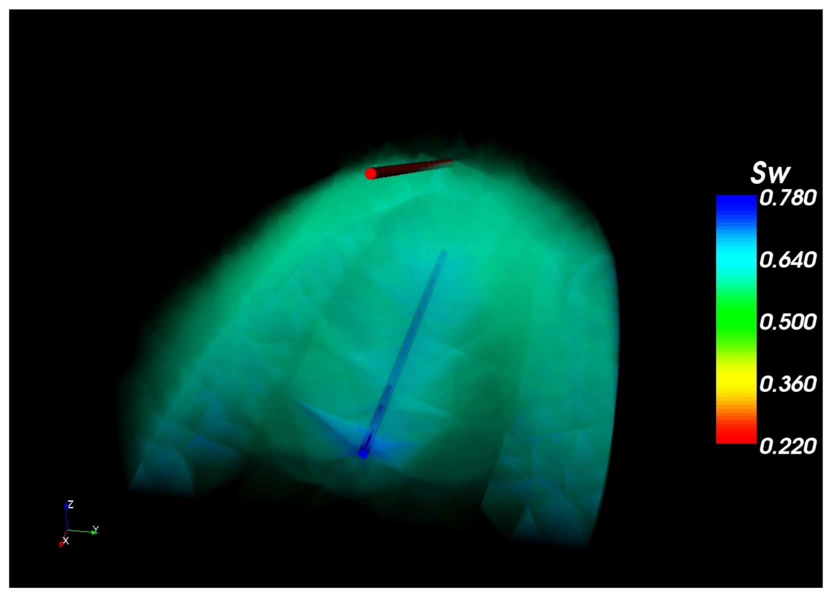
Lower permeability inner core affords the possibility of water encroachment and sweep of the outer core. Higher permeability inner core gets the water to the production well, preventing efficient displacement in the outer core.

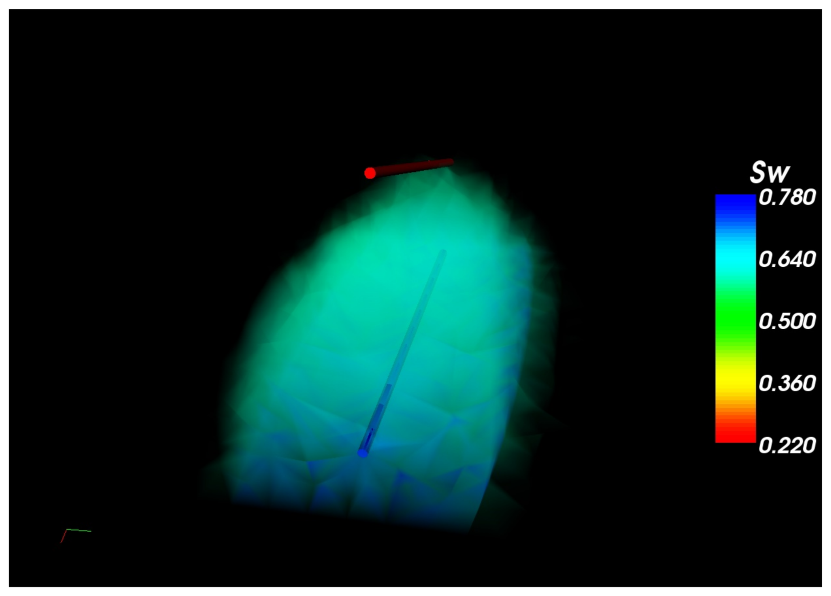
Water saturation distribution at 500 days.



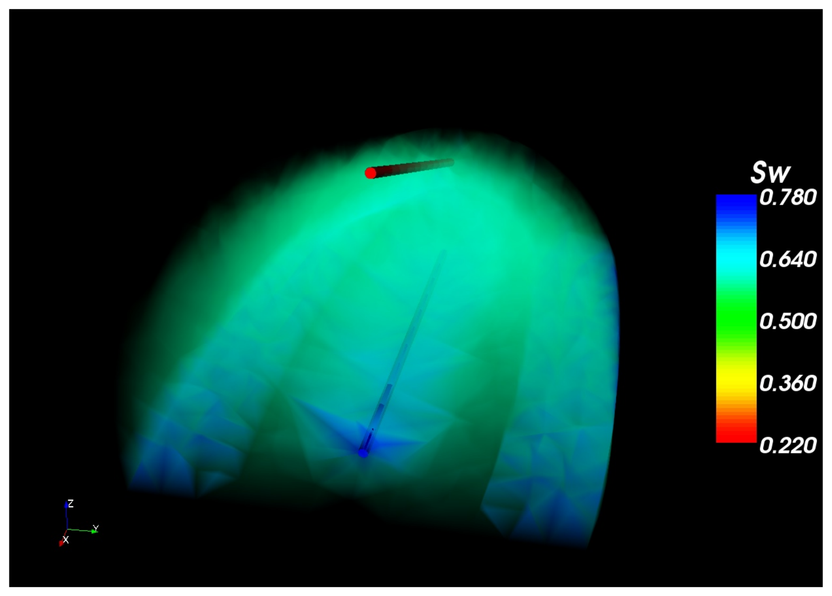


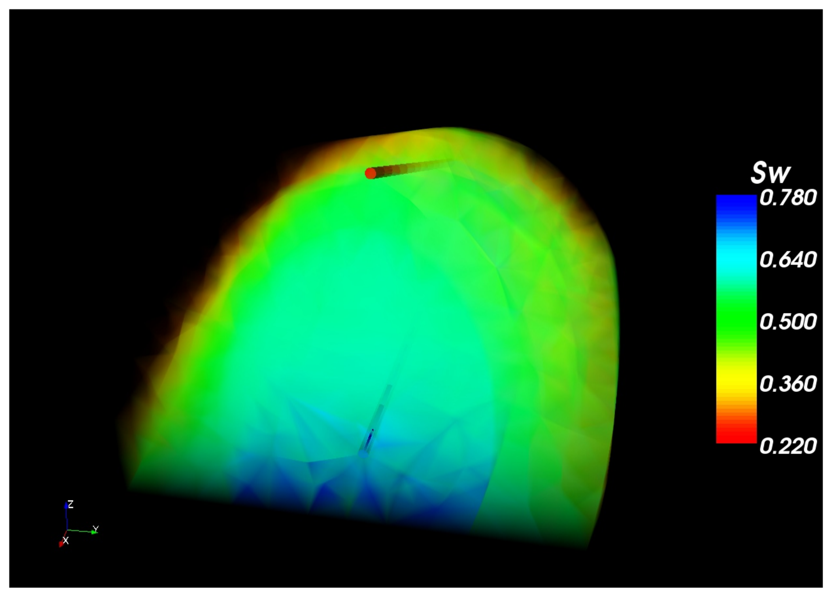
Water saturation distribution at 1000 days.





Water saturation distribution at 2000 days.





Oil production rates and cumulative oil productions of Case I and II.