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Well Placement Optimization Using a Basic Genetic Search Heuristics Algorithm and a Black Oil Simulator

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Abstract

In petroleum reservoir management, the essence of well placement is to develop and maintain reservoir pressure in order to achieve maximum production for economic benefits. Large production can be achieved with the placement of multiple wells but this approach is capital intensive and inefficient for the development of a reservoir. A preferable option is the optimal placement of production and injection wells so as to fully capitalize on the imbedded hydrocarbons at a relatively decreased capital investment. The aim of this study is to use developed algorithm and a black oil simulator to place wells in the zones for optimal recovery in the reservoir. Optimal production was determined out of eight scenarios created from well placement in a hypothetical reservoir (finch reservoir) using a black oil simulator, alongside an algorithm developed with java for determining the best possible locations for well placement, taking into consideration the reservoir permeability, fluid saturation, and pay zone thickness. The results of this study reveal that well placement using the engineering judgment coupled with the application of the algorithm using a black oil simulator results in better production compared to other scenarios which consider the combined effect of algorithm and black oil simulator alone.

Keywords

Well Placement, Genetic Algorithm, Reservoir Simulator, Production Analysis, Injection Analysis

1. Introduction

Well placement can be described as the positioning of production and injection wells in an oil field to optimally deplete the reservoir. Knowledge of this key concept is a necessary requirement to effectively utilize the reservoirs natural pressure; this will ensure optimal drainage of the saturating hydrocarbons [1]. A decision on optimal well location is normally a tedious process which is affected by geologic complexities, engineering limitations and economics. These factors must be properly accounted for to avoid the adverse effect on the general performance of the reservoir and place limit to the recoverable hydrocarbon reserves. An interesting approach to solving the problem of well placement is the use of quality mapping; it is a two-dimensional representation of multiple flows through a porous medium. In the utilization of quality maps, two approaches are present: the basic quality map approach (BQM) and the modified quality map approach (MQM) [2] [3] [4].

Another popular method of deciding well architecture is the utilization of simulation software to decide well placement positions within a reservoir. This approach utilizes information from seismic surveys, measurement while drilling, special core analysis and also logging to create an electronic sample of the reservoir. This method is applied to establish the most efficient depletion scheme which may be utilized to produce a well [5].

In order to ensure the optimal productivity of a reservoir, some of the paramount factors which must be taken into account are the location, timing and types of well utilized for a field development project. The positioning of production and injection wells is a very critical aspect of oil field development planning (FDP), a phase which deals with the acquisition, analysis and integration of data from geologists, geophysicists and reservoir engineers for the optimal development of an oil field [6].

Detail work has been done on optimal well placement focusing on the interaction within the surface facilities or the reservoir [7]. Henry *et al.* [8] used combined knowledge of geological model and reservoir properties obtained from log data to build a 3-D reservoir property model, considering facies in identifying sweet spots for optimizing well placement. The integration of the geological and reservoir model assumed negligible interaction between wells which actually reduces complexity and possible computation time, this computation may limit the wide application of the result. The method of using quality maps alongside integration programming solution was implemented by [9]; the use heuristics algorithm technique offers a better solution efficiently for complex computational problems requiring large solution times [8]. Marques *et al.* [10] investigated the placement of well using reservoir drive mechanisms (gas cap and water drive) and aquifer size in three different locations: right below the oil water contact, at the middle of the oil column, and right above the oil water contact. The integration of detail engineering judgment and heuristic algorithm will possibly provide efficient result in the well placement.

The use of heuristics is fast becoming a popular methodology in the optimization of well placement [11]. With advancement in the speed of computing, more variables can be accounted for with the perspective of a larger scope for better computational result within relatively smaller time frame. Yeten *et al.* [12] utilized a Genetic Algorithm (GA) to maximize well location, well type and trajectory for directional wells. Asides that, they also improved and incorporated software based on nonlinear conjugate gradient algorithm to further enhance intelligent well controls.

Genetic Algorithm (GA)

In the field of synthetic intellectual competence, a GA is a search heuristic that mirrors or mimics the approach of normal decision. This heuristic (also occasionally called a metaheuristic) is routinely used to create accommodating responses for development and chase problems [13]. Genetic algorithms fit in with the greater class of Transformative Algorithms (TA), which make answers for headway issues using systems moved by normal advancement.

Genetic algorithms find application in bioinformatics, phylogenetic, computational science, Civil engineering/construction, budgetary angles, science, creating, math, material science, pharmacometrics and diverse fields [14].

This study involves the use of 3-D reservoir simulator to generate data which is then run through a heuristic program. Next, the result is coupled with engineering judgment in order to generate an optimal solution to the well placement problem. Well placement is extremely a challenging task of reservoir development, nevertheless, the application of the engineering judgment to the data generated from the simulator integrated with the heuristic algorithm, helps in determining the optimum infill well location, and field development plan resulting in the substantial increase in the productivity and reserves. This principle is profitable in wells with complex fluid low and heterogeneous in nature. The heuristics for automated optimization is used for benchmarking performance of well placement. The optimal well placement into areas of the reservoir maximizes more flow area of fluid saturation, resulting in cumulative oil recovery, reduces level of uncertainty, and this in general will possibly reduce unnecessary cost that may result from inappropriate well placement.

2. Materials and Methods

In this study of well placement in a finch reservoir, a 3-D Reservoir simulator was used to build the model, alongside a genetic algorithm created with the use of the java compiler program for optimum placement of the well, with the engineering judgments as guiding factors in order to maximize the reservoir productivity. The varying permeability, porosity and pay zone thickness at different points in the reservoir were used in the developed algorithm to compute the injection and production points.

The injection and production data from the genetic algorithm are then inputted into the simulation in order to place the wells and assess the benefits from a multiple configuration being considered by the genetic algorithm and also to obtain the best recovery factor. The efficiency of all scenarios evaluated is then considered in terms of the recovery factor, production profiles and evolution of water cut.

2.1. Engineering Judgment

Engineering judgment involves the exploitation of natural phenomena present in the reservoir. It is based on reservoir parameters such as: The presence of faults, fractures, anisotropy, connectivity, reservoir extent, flooding pattern selection, permeable zone exploitation, fluid distribution within reservoir, injection fluid selection, exploitation of reservoir geological features, gravity drainage effect, well spacing and positioning. In applying the engineering judgment, the well placement results from simulator and the GA are modified by placing injection and production wells in the following regions: unswept areas and areas which are not optimally drained by the GA derived well placement.

2.2. Basic Model Information

The model parameters used for this work is as shown in **Table 1**, the data extracted from the reservoir model involves the step-by-step selection of cellblocks and then reading measurements of individual cellblock parameters such as:

Table 1. Basic model information.

Simulation Type	Simulation Start Date	Model Dimensions	Units	Run Type	Grid Option	Geometry Type	Number of Producer Wells	Number of Injector Wells
Black Oil	1-Jan-15	31, 12, 3	Fields	Normal	Cartesian	Block Centered	8	8

- Position (x,y,z)
- Pressure (psia)
- Depth (ft)
- Thickness (ft)
- Permeability (millidarcy)
- Oil saturation (%)
- Water saturation (%)

The objective function of the genetic algorithm describes the value utilized during computing to ascertain the "fitness" of an individual cellblock being considered. The objective function being considered in this work is a crude zonal representation of adequate reservoir properties and well characteristics.

Parameters that influence positioning of production and injections wells are extracted from each grid cells and presented in **Tables 2-5**.

Table 2. Injector/producer locations with WPI-Case 1.

Case 1					
x	y	Producer Index	x	y	Injector Index
	7	2×10^{11}	17	3	35,093
21	7	2×10^{11}	20	3	33,473
16	7	2×10^{11}	14	3	29,663
19	8	2×10^{11}	7	3	27,019
22	7	2×10^{11}	22	3	25,486
24	7	1×10^{11}	18	4	24,702
9	7	1×10^{11}	15	4	21,417
20	8	1×10^{11}	13	4	20,481

Table 3. Injector/producer locations with WPI-Case 2.

Case 2					
x	y	Producer Index	x	y	Injector Index
18	7	2×10^{11}	17	3	35,093
15	7	2×10^{11}	15	3	29,775
17	8	2×10^{11}	17	4	26,600
24	7	1×10^{11}	18	4	24,702
21	8	1×10^{11}	8	3	20,643
9	8	1×10^{11}	19	4	19,342
22	8	9×10^{10}	17	5	16,869
19	9	9×10^{10}	26	3	14,605

Table 4. Injector/producer locations with WPI-Case 3.

Case 3					
x	y	Producer Index	x	y	Injector Index
18	7	2.162×10^{11}	17	3	35,093
14	7	1.837×10^{11}	13	3	29,061
15	8	1.352×10^{11}	21	3	24,937
20	8	1.232×10^{11}	13	4	20,481
7	7	9.449×10^{10}	8	4	18,043
19	9	8.738×10^{10}	26	3	14,605
16	9	7.174×10^{10}	25	3	13,278
9	9	6.032×10^{10}	7	5	11,127

Table 5. Injector/producer locations with WPI-Case 4.

Case 4					
x	*y*	Producer Index	*x*	*y*	Injector Index
18	7	2.162×10^{11}	17	3	35,093
19	8	1.603×10^{11}	7	3	27,019
9	7	1.242×10^{11}	15	4	21,417
25	7	1.01×10^{11}	6	4	18,047
29	7	8.692×10^{10}	21	4	14,506
24	8	6.541×10^{10}	9	4	12,323
28	8	5.833×10^{10}	23	4	10,707
8	9	4.775×10^{10}	24	4	9424

Furthermore, the suitability of each cell location is ascertained using the derived fitness function. This is given as Equation (1).

$$\aleph = W_{\text{p}} * R_{\text{p}} \tag{1}$$

where:

$\aleph$ = Well placement index and,

$$W_{\text{p}} = \text{well parameter} = \frac{1}{\text{Depth}} \tag{2}$$

R_{p} = reservoir parameters

$$R_{\text{p}} = K_x K_y h\left(1 - S_{\text{w}}\right) P \quad \text{for a producer} \tag{3}$$

and

$$R_{\text{p}} = \frac{\left(K_x K_y h S_{\text{w}}\right)}{P} \quad \text{for an injector} \tag{4}$$

Thus, for a producer, the well placement index is derived by combining Equations (1), (2) and (3) and is given as:

$$\aleph_{\text{prod}} = \frac{K_x K_y h\left(1 - S_{\text{w}}\right) P}{D} \tag{5}$$

And similarly, for an injector, the well placement index is derived by combining Equations (1), (2) and (4) and is given as:

$$\aleph_{\text{inj}} = \frac{K_x K_y h S_{\text{w}}}{PD} \tag{6}$$

Objective Function Parameters

1) *Reservoir*

Reservoir parameters considered for the formation of the objective function (for individual cells):

- Pressure
- Saturation (oil and water)
- Thickness (*h*) and
- Permeability in the *X*, *Y* and *Z* (K_x, K_y and K_z), directions.

Based on these parameters, an index which is a multiple of the parameters above was created, which directly defines the favorability of each position.

2) ***Well***

Well parameters considered for the formation of the objective function (also for individual cells):

- Depth

This approach assumes other well variables are constant. Hence the most defining factor is the depth the well would reach in the reservoir. It is important to state here that the increase in cost of drilling a well is directly proportional to the depth of the well (*i.e.* greater depth = greater cost).

3) ***Production analysis***

The production analysis for the genetic algorithm involves the use of the objective function with the reservoir parameters dependent on multiple of pressure, oil saturation, permeability in the x direction (vertical well consideration), the thickness of the contact cell and depth. These considerations are required in order to account for favorable production well placement. The genetic algorithm is aimed at the identification of well combinations, which would give the best cumulative oil production.

4) ***Injection analysis***

Injection analysis inputted into the genetic algorithm, involves the use of the objective function with the reservoir parameters dependent on the multiple of thickness of the contact cell, permeability in the x direction (also considering vertical injection wells). These factors being considered are highly important in the consideration of injection parameters.

The data is inputted into the algorithm to discover the positions which have the highest injectivity indices.

3. Results and Discussion

The model is of two different categories: the study case (with the singular use of GA) and the case with the use of GA and reservoir engineering judgments as a major contributing factor. Each case is evaluated using a time step of 15 years and subsequently ranked based on field oil production rate, water breakthrough time, field pressure and recovery factor.

3.1. Case Scenarios

Following the derivation of the well placement indices for all the cells in the vertical direction in order to guide the selection of various cases, the well spacing is not taken into consideration for cases 1 to 4.

Cases 1 to 4 (8 Producers and 8 Injectors)

Well placement for cases 1, 2, 3 and 4 are solely based on the results obtained from the placement indices. This is derived using the well placement index equations for both producers and injectors. After obtaining the results, location of wells for the four cases are done by sifting through the data in a progressive manner. The locations of production and injection wells with their corresponding well placement indices are shown in Tables 2-5.

3.2. Discussion and Analysis of Simulation Results

Following the acquisition of well placement locations for the four cases, the models for each of them was then incorporated into the grid. Simulation for production and injection forecast was then performed for each of the four cases. The results of the simulation are shown in subsequent figures and tables.

Figure 1 shows the distribution of permeability in the *x* direction and Figure 2 displays the saturation of oil in the grid block used in the simulations. Figures 3-6 show the locations of the wells in the grid with the post-simulation oil saturation distribution. All the four cases have different sweep efficiencies. Figures 7-9 show the field oil production, the cumulative field production and the recovery factor for all the cases. From Figure 9, it can be observed that cases 3 and 4 have the highest recovery factors somewhere around 34% of the initial oil in place. Whereas, cases 1 and 2 have much lower recovery factors. This is most likely due to the wells positioning in the very sweet spots in cases 3 and 4 as directed by the well placement equations. The wells in cases 3 and 4 cover a larger area and hence yields higher sweep efficiencies (The sweetness of the combined producer and injector WPI of the cases reduces from case 4 down to a minimum in case 1). Noting that the development costs for all cases are more or less the same as the fiscal framework, number of wells and surface facilities for all cases are the same. The field oil production rate and cumulative production plots reveals sufficient economic evaluation. Figure 10 shows the evolution of field water cut with time. Whereas, cases 3 and 4 seem to have higher water cut compared to cases 1 and 2, their recoveries (Figure 9) and cumulative oil production (Figure 8) are higher. This is because, some of the production wells in cases 1 and 2 get to the upper limit for the maximum allowable water cut and then the wells are shut-in. This leads to a corresponding reduction in total field water production for cases 1 and 2.

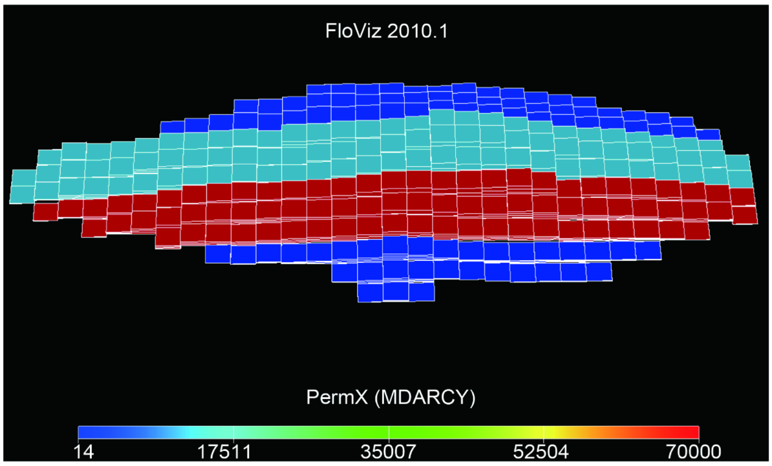

Figure 1. Permeability distribution (X direction).

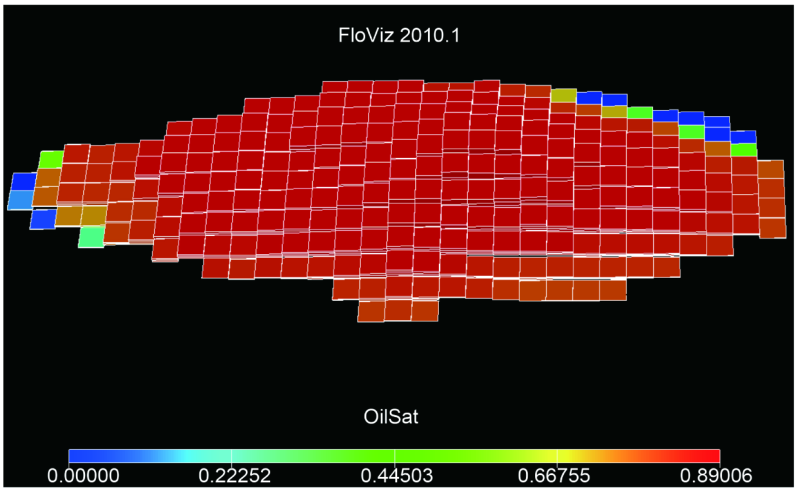

Figure 2. Grid showing oil sat profile at simulation start.

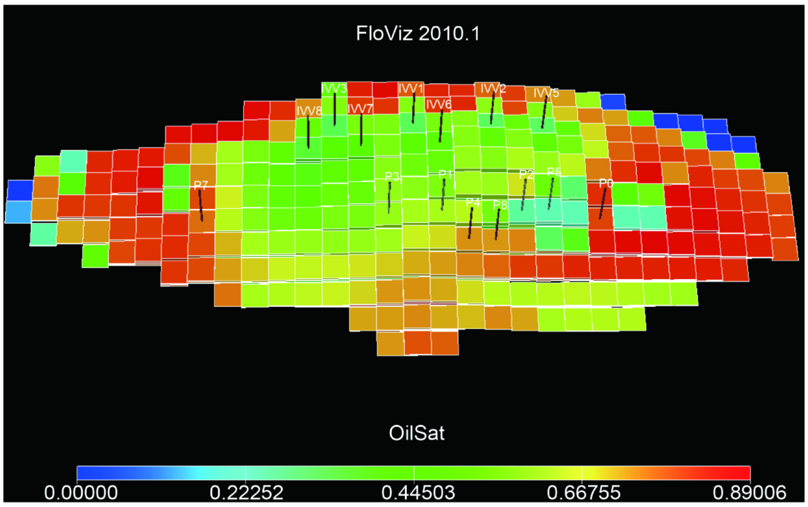

Figure 3. Well location/post-production oil sat distribution—case 1.

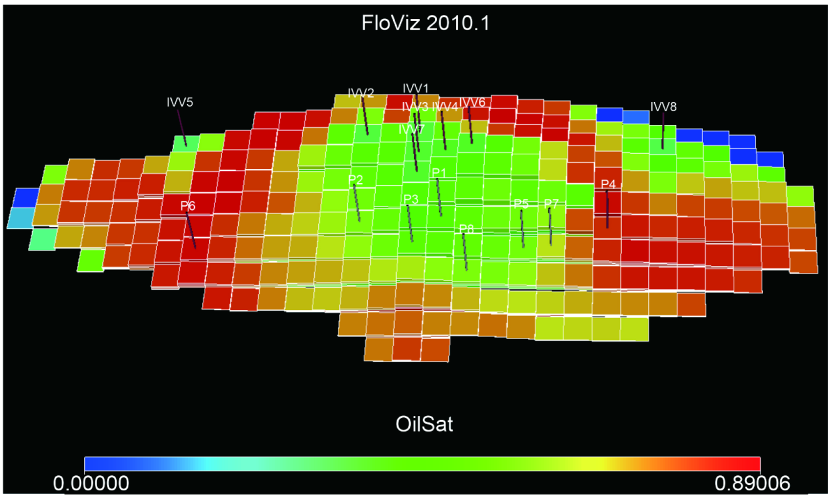

Figure 4. Well location/post-production oil sat distribution—case 2.

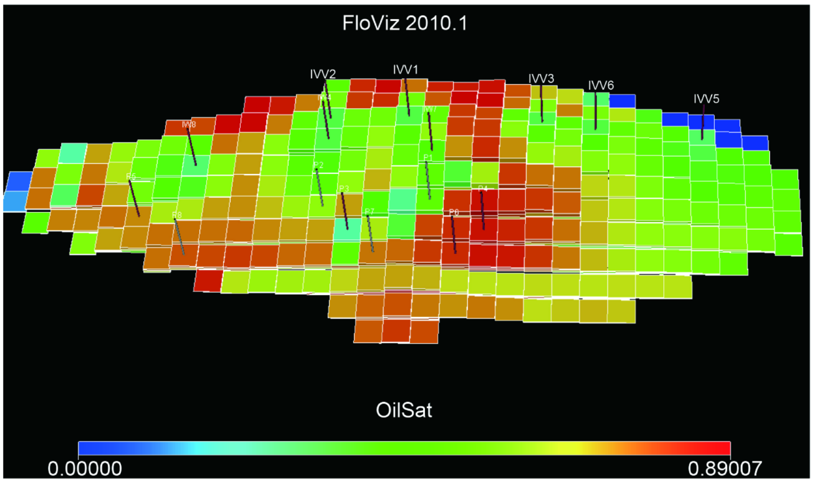

Figure 5. Well location /post-production oil sat distribution—case 3.

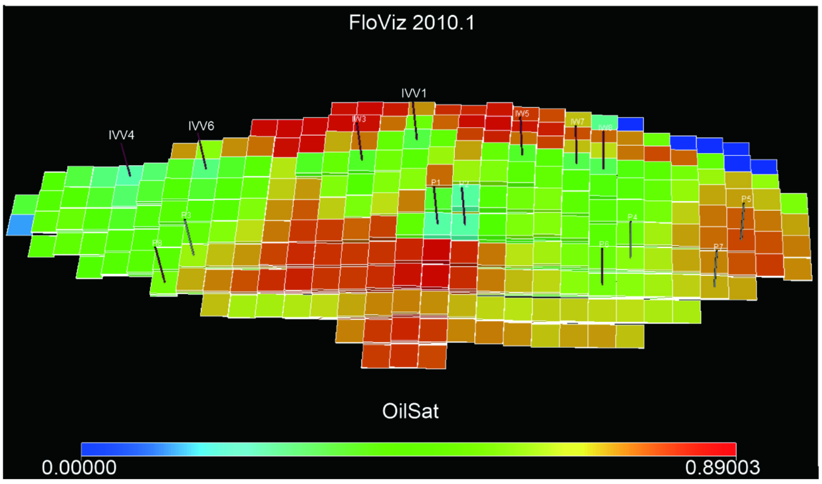

Figure 6. Well location/post-production oil sat distribution—case 4.

4. Conclusions

The following are evident looking at the results obtained in **Figures 7-10**:

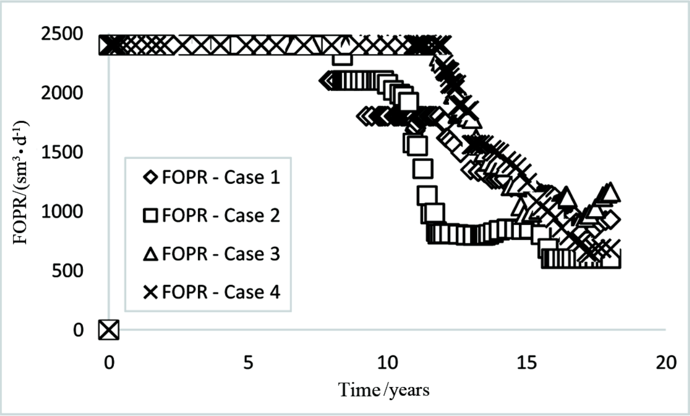

Figure 7. Field oil production rate vs time—all cases.

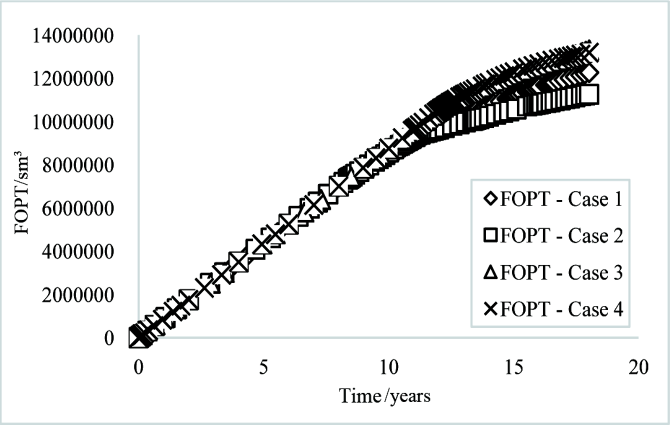

Figure 8. Cumulative field oil production—all cases.

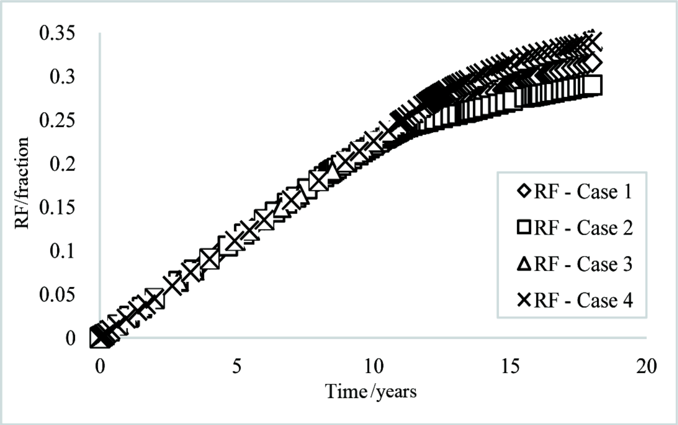

Figure 9. Evolution of recovery factors—all cases.

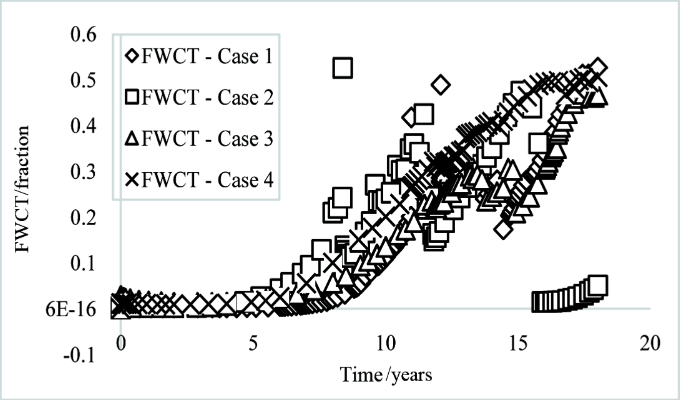

Figure 10. Field water cut—all cases.

The use of the heuristic algorithms in the determination of well position provides a leeway for the optimal determination of well placement according to the set parameters of the algorithm. The combination of the genetic algorithm and the reservoir simulator in the two optimization frameworks improved the positioning of well. The FOPT and RF results from the simulator show that the best case is case 1 which is the optimal case proposed by the algorithm. The involvement of geological constraints (anticlines, faults, fractures etc.) into the solution of the genetic algorithm helped in providing a more suitable analysis. In the analysis, an improved solution on the well positioning was obtained from the smaller sample size implemented through the genetic algorithm.

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