PRODUCTION STRATEGY OPTIMIZATION OF AN OILFIELD

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Abstract. The present work focuses the study of a particular area within an oilfield located in Central Asia – an area which is being developed, with a clear production strategy and oil wells in production. With just over a decade until the end of the concession period – and given the vast investment already made, namely on surface facilities – it’s crucial to implement a methodology to optimize the production strategy and therefore maximizing the oil recovery and the profitability of the project.

The methodology used in this work used streamlines simulation and the quality map as tools for numerical simulation, making the optimization process faster and more objective. Streamlines have proven their usefulness when combined with the analysis of the flow of fluids between producing and injector wells, and their utility to determine the efficiency of injector wells. Regarding the reservoir quality map, the greater advantage has proven to be its ability to represent in a quantitative way the production potential of the reservoir, enabling a quick tracking of the best and worst production areas for the drilling of new wells.

Considering the maximum capacity of the surface infrastructures involved (as well as the operational and financial constraints of the project), it was applied to this field a specific methodology that enabled to analyze optimal production strategies in two different investment scenarios – with and without the drilling of new wells – both aimed at maximizing the volume of recovered oil and the profitability of the project as a whole until the end of the concession period.

KEYWORDS: Production Fields, Production Strategy, Production Strategy Optimization, Numerical Simulation, Reservoir Quality Map, Streamlines Simulation.

1. Introduction

Production strategy optimization is a complex procedure, requiring detailed behavior analysis of the production and injection wells in the field to determine, among others, which wells are subject to change. The possible changes are the conversion of producing wells in injectors, the change in completion and operating conditions of the wells, the closure of them, etc. In addition, field areas with presence of accumulated oil which have the possibility of their recovery through new producers and/or injector wells, should also be studied.

There are a large number of variables that influence the optimization process such as the properties of the reservoir rock and fluids, production data, pressures, etc. This complexity increases the difficulty of mathematical optimization methods due to the large computational effort required in the modeling and reservoir simulation process. An efficient and effective integration of simulation models and technologies, surface facilities and operations, enables continuous optimization of the development plan implemented by the teams responsible for managing an oilfield.

In general, for the definition and optimization of production strategies, the reservoir engineer takes into account, in addition to economic factors, the maps of reservoir properties such as fluid saturation, permeability, porosity, among others. Thus, other important parameters such as some dynamic factors of interaction between the fluid properties and rock during production may not be taken into account. In order to try to consider all of the dynamic interactions in the definition and optimization of the production process and strategies to reduce the inherent subjectivity of these processes, there is the need for the existence of techniques and decision support tools.

Furthermore, as the quality and quantity of information increase, it is interesting the use of additional tools in order to refine and improve the knowledge of the reservoir. As more information is
available, a greater refinement of the production strategy is justified. This motivates the use of additional techniques such as streamline simulation and quality map. These tools, described below, are support techniques that help more detailed analysis.

2. Supporting Tools

2.1 Numerical Simulation - The numerical simulation is the method most used in reservoir engineering to study the behavior of fluid flow in oil fields and it was used in this work since it’s the most efficient method available. Thus, all the forecast scenarios and modifications suggested by streamlines simulation and the quality map were made and tested by this method.

The numerical simulator used in this paper was the commercial simulator ECLIPSE 100™ using Petrel Reservoir Engineering for data creation and presentation of the simulation results. This simulator was used for pressure curves analysis, daily flows and wells cumulative production, to study the various forecast scenarios of production and application of different operational parameters, among others. With the production data provided by this simulator, the field Net Present Value (NPV) and the NPV from each producer well were calculated and decided what strategy to implement in order to be maximized its value.

2.2 Quality map - Quality map is a bi-dimensional representation of several three-dimensional properties of a reservoir. The idea is to try to encapsulate a set of properties in a unique property, or a quality index. Besides the frequent use of quality map in drained strategy optimization, quality concept may be also applied in other areas as for example, to compare reservoirs, to rank stochastic realizations and to incorporate reservoir characterization uncertainty into decision making, such as choosing well locations, with fewer full field simulation runs.

Quality map is a tool that incorporates all the properties of the rock and fluids, and the dynamic interactions that occur during the production/injection wells in the field, making the analysis more efficient. Thus, the production potential of each region in a given reservoir may be measured and plotted as a map, where the regions are identified by the higher and lower potential location, respectively, for producer and injector wells in the field. The quality index is calculated by an objective function, which may be the cumulative total production (Np) or the Net Present Value (NPV) calculated for each well allocated to the region it represents. This index ranges from 0 to 1, where lower values representing lower quality levels, i.e., low production potential.

There are several methods of generating a quality map. In the present study was used the numeric method proposed by Cruz et al (1999) and was applied the simulation process used by Cavalcante Filho (2005), which consists of simulated simultaneously a group of vertical wells in the reservoir with the help of water injection wells.

2.3 Streamline Simulation - The technique of streamline simulation decouples computation of saturation variation from the computation of pressure variation. The basic principle is a coordinate transformation from physical space (3D) to one dimension trajectory (streamline) along which displacement processes is computed. Saturation equation is solved along one dimension. Streamlines are one dimensional flow paths in the reservoir and have flow rates with a distinct origin and destination. Streamlines can represent drive mechanism to a producer or flux from an injector. When streamlines have the same origin and destination, they can be grouped or summed into bundles. Therefore, if origin and destination is a well pair, the relationship between the wells (injector/producer) is quantifying in terms of flow rate. These features of streamline simulation offer a powerful tool in applications such as water flood management and strategy optimization (Grinestaff, 1999; Thiele, 2003; Guimarães, 2005). The streamlines simulation is used in this paper as an auxiliary tool for the study of reservoir water flow, determining the relationships between the producer and injector wells. This tool is also used in the optimization process, using the information on the efficiency of injector wells to adjust the flow rates injected into each well.
3. Methodology

The present work is divided into three (3) steps, where the first (Step 1) aims to study the past behavior of the field, analyzing their production, injection and reservoir data, and adjust the production forecasts to historical data; the second (Step 2) aims to optimize the initial production strategy with the existing wells in the field; and the third step (Step 3) analyze and optimize the production strategy, allowing the drilling of new wells in order to increase production and maximize the existing surface facilities utilization.

The methodology presented in this paper consists of the integration of three tools: finite difference reservoir simulation, streamline reservoir simulation and quality map. In Fig. 1 is presented the general methodology flowchart developed for the optimization of the field production, applied in Steps 2 and 3.

![General methodology flowchart](Figure 1 - General methodology flowchart)

Next, it is described in greater detail, the several steps which were followed in this study.

**Step 1** - Evaluation of the base case to assess the main characteristics of the field and well production, such as oil rate, water rate, water cut, gas-oil rate, bottom hole pressure (BHP) and average reservoir pressure. At this stage, the forecast production was adjust to production history, having found that some of the operational parameters applied in the field, such as the producing wells minimum BHP did not follow the basic rules of good practice in the reservoir management and thus need to be adjusted. With the arrangements made, the predictions have become more reliable, so it can be done in a more precise way, in Step 2, the performance analysis of each well in the field.

**Step 2** - In this part of the work it was applied a production optimizing methodology to the existing wells in the field (16 producers and 7 injectors) until 2024, while verifying the efficacy of the quality map and streamlines simulation. Quality map was generated in order to classify producer wells and streamline simulation was ran in order to measure the relationship between producer wells and injector wells. This information was used to compute injector efficiency and to know the influence of a given injector associated to a given producer.

Subsequently, the economic field analysis was made for the forecast period of the initial production strategy and rated the performance of each of the producing wells, based on the values of NPV, Np, Wp (cumulative water production), Gp (cumulative gas production), Qo_m (average oil flow) and Mp (reservoir quality index taken from the quality map). The index classification for producer wells was defined by Schiozer et al. (2002). The index W (W=Wp/Np), used by Guimarães (2005), was used to take into account the study of water in the field. Also, it was considered the injector efficiency (Ef) which is derived from streamline simulation and is suitable to analyze injector wells. This index is obtained through the ratio between the volume injected by a given injector and the volume of oil produced as result of the injection.

To guide the strategy refinement, the classification map showed in Figure 2, based on the work of Schiozer et al. (2002), was used. In this case, the change order was defined considering the priority need for modifications in wells with low values of NPV, high values of W, low average production flow rates and located in areas with low quality reservoir. Four main regions are defined based on two main indexes: NPV and Np. Red region, for example, it is characterize by NPV low or mean (NPV b/m), and Np low or mean (Np b/m). Each major region is divided in smaller regions based on others indexes. Based on this classification, priority orders for modifications in the wells are established. Numbers inside white ellipse represent a sequence of priority.
Based on the previous analysis and on the classification map, a set of changes is defined. It was considered that each production well could have up to three modifications to be evaluated (closing the injection well correlated, conversion of producing well in injector and closure of production well). Changes are tested and, if it improves the results (higher NPV), are implemented. Otherwise, the set of changes is checked for remaining changes. The set of changes showed in Figure 1 (bounded by dashed line) is related to a given producer well. However, the injector well associated to the tested producer well is also tested. For example, if the producer well is shut, then the injector associated is also shut.

The end of the optimization process applied in this study occurred when all production wells passed by modification and/or proposed closure tests and all the injectors wells correlated with producers that were closed have your closing tested. While all these stopping criteria were not satisfied, the optimization process has not reached its end. Another criterion with which it was considered the end of the process was the set of proposed changes have not led to an increase of the field NPV.

Some general aspects related to the methodology are: (1) Finite difference simulation is used as the main tool in the process. All quantities necessary to the process, such as field/well production and field/well water injected are generated through this technique; (2) The criterion for choosing the optimized scenario was the maximization of Net Present Value of the field (NPV), obtained by numerical simulation corresponding to the production period 2013-2024; (3) All calculations of volumes of oil, water and gas produced, volume of injected water and NPV values of the field and the wells were calculated for the forecast period of behavior, phase where the changes are implemented (2013-2024).

Finally, after choosing the optimal scenario, the analysis of the efficiency for injector wells was made using streamlines simulating in order to be redistributed more efficiently the fixed volume of water injected (2,384 bbl/d) from the wells.

**Step 3** - In this last step of the work a production strategy was set for the same area of the field through the optimization method used previously, including new wells in the field. The aim was to maximize the production of oil by the end of the concession period, taking into account the capacity of the existing surface facilities.

Initially, from the reservoir quality map generated in the previous step, the new production and injection wells were located in areas that had, respectively, the best and worst quality values. After choosing the scenario with the new wells to take advantage of the facilities maximum capacity (maximum liquid daily production=6,000 bbl/d and maximum gas daily production=1,000 MSCF/d), the strategy was optimized through the methodology used in Step 2, testing the changes in the wells to be maximized the profitability in the field (maximum NPV).
4. Field Application
This work focuses on the production strategy of Phase 1 area in Maka oilfield, located onshore in Central Asia, with production beginning in 2000 and the end of the concession scheduled for 2024. The actual strategy for this phase consists of producing 16 wells, supported by 7 water injection wells, vertical and horizontal (Fig.3). The historical period is 13 years (January 2000 to January 2013). The STOIIP of the field is approximately 270 MM bbl.

For this study it was used a sector that includes the Phase 1 area from the full-field model provided by Partex Oil and Gas (Fig.4). This dynamic model was built based on reservoir sands of the Lower Cretaceous (Aptian) of the field, with an average thickness of 25m. This is a model for highly heterogeneous reservoir, partially fractured and where it is considered the existence of a non-actuating aquifer in the reservoir.

The sectorial model is composed of a grid of 191,970 blocks (79x81x30) and each block has approximately 100x100m with variable-depth, about 1m.

5. Results and Discussion
Regarding the study of Maka field, it can be said the production strategy optimization that was made in Step 2 and 3 was successful. In Step 2 of the study, which was intended to optimize the production strategy of the field considering only the existing wells, the methodology allowed for an increase of 14 MM USD, with the optimization phase and including the redistribution of injected flow in the injector wells. Since it was only considered the existing wells, the quality map was built to be used exclusively as an additional variable for classification of producing wells for the process of optimization of production strategy (Fig. 5). The fluid flow study results for Base Case Scenario are presented in Tab. 1. In this step the streamlines simulation results have served to the optimization process and subsequently to the effectively redistribution process of the flow injection at the field.

![Figure 5 – Quality map used in the study](image)

Figures 3 and 4 – Wells location in the sector and sector positioning in the full field
Table 1 – Streamlines simulation results (Base Case Scenario – Step 2)

<table>
<thead>
<tr>
<th>WELL</th>
<th>33H</th>
<th>33V</th>
<th>44V</th>
<th>45V</th>
<th>46V</th>
<th>47V</th>
<th>48V</th>
<th>49V</th>
</tr>
</thead>
<tbody>
<tr>
<td>27V</td>
<td>-</td>
<td>13%</td>
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<td>30V</td>
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<td>-</td>
<td>-</td>
</tr>
<tr>
<td>36V</td>
<td>1%</td>
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<td>-</td>
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<tr>
<td>39V</td>
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<td>42V</td>
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<td>47V</td>
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<td>48V</td>
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<tr>
<td>53H</td>
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<tr>
<td>54H</td>
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<tr>
<td>TOTAL</td>
<td>0%</td>
<td>100%</td>
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<td>100%</td>
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</table>

The main parameters resulting from the changes held in the optimization process in Step 2 are shown in Table 2. It is noted that the optimal scenario obtained from the simulation 9, result of the simulation 1 which in turn was obtained from the Base Case optimization, have been maintained since it led to an increase in the field value NPV. Scenario Simul_29, where the injected flow redistribution was tested given the efficiencies calculated for each injector wells, shows an increase in the amount of oil accumulated compared to Simul_9 and also an increase by more than 4 MM USD in the NPV field value, which justifies the choice of this production scenario as the final optimization scenario from Step 2.

Figure 6 compares the results of the NPV value of the strategies of the Base Scenario, optimized scenario (Simul_9) and redistributed flows injection scenario (Simul_29), obtained during the prediction of behavior in Step 2.

Table 2 – Results from the changes held in optimization process - Step 2

<table>
<thead>
<tr>
<th>Simulation</th>
<th>Observed Behavior</th>
<th>Proposed Modification</th>
<th>Modified Date</th>
<th>Np (bbl)</th>
<th>Wp (bbl)</th>
<th>NPV (USD)</th>
<th>RF (2000-2024)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base Scenario</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>5,804,624</td>
<td>4,478,848</td>
<td>270,373,474</td>
<td>5,36%</td>
</tr>
<tr>
<td>1</td>
<td>Well 30 shows low values of Np and Wp.</td>
<td>Close correlated producer</td>
<td>02-01-2013</td>
<td>5,936,647</td>
<td>4,219,927</td>
<td>275,968,663</td>
<td>5,41%</td>
</tr>
<tr>
<td>2</td>
<td>Well 36 shows low values of Np and Wp.</td>
<td>Close correlated injector</td>
<td>02-01-2013</td>
<td>6,078,038</td>
<td>3,526,240</td>
<td>280,388,870</td>
<td>5,46%</td>
</tr>
<tr>
<td>3</td>
<td>Well 39 shows low values of Np.</td>
<td>Convert to injector</td>
<td>02-01-2013</td>
<td>6,135,276</td>
<td>3,654,983</td>
<td>284,572,126</td>
<td>5,48%</td>
</tr>
</tbody>
</table>

Based on the result of the simulation 9 (NPV maximum), redistribution of the flow in the injectors according to streamlines information.

In summary, of the 16 producing wells in the field, 2 will be converted to injectors from 2013 and will only be drilled 20 new production wells and 17 injectors in 2016 (Fig. 8).
As found from the results presented below (Table 3 and Figure 9), the optimization process ends with the simulated scenario Simul_76 which maximizes the value of the field NPV (448 MM USD). Despite the lower number of producing wells in the Optimal Scenario strategy, compared to the Base Scenario strategy, there has been an increase in oil production in the field. This fact is quite indicative of the importance that this type of simulation study has on projects, allowing the study of different production strategies scenarios and the interaction between the field wells, avoiding unnecessary investments.

Table 3 – Results from the changes held in optimization process - Step 3

<table>
<thead>
<tr>
<th>Simulation</th>
<th>$N_p$ (bbl)</th>
<th>$W_p$ (bbl)</th>
<th>NPV (USD)</th>
<th>RF (2000-2024)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base Scenario Step 3</td>
<td>11,719,254</td>
<td>8,884,323</td>
<td>411,005,93</td>
<td>7.54%</td>
</tr>
<tr>
<td>Simul_76</td>
<td>11,899,394</td>
<td>8,105,864</td>
<td>448,703,733</td>
<td>7.61%</td>
</tr>
<tr>
<td>Difference</td>
<td>180,143</td>
<td>-778,459</td>
<td>37,697,802</td>
<td>0.07%</td>
</tr>
</tbody>
</table>

Figure 9 – NPV’s scenarios compared obtained in Step 3

However, to be implemented the strategy that maximizes the NPV value in Step 3, an investment to increase the capacity of water injection facilities of 2,384 bbl /d to 6,700 bbl / will have to be made. This cost must be considered in the choice of strategy to apply at this stage of development. Finally, in the decision-making strategy for the final stage of production of the field is important to take into account the high investment that will be needed to implement the optimal strategy in Step 3 This value is approximately USD 78 MM on the cost CAPEX of new wells in 2016.
6. Conclusions

The drainage optimization process is a complex task due to high number of control variables involved. Using the integration of three important tools, confirming their potential, this paper applied a methodology that can contribute for the process. Although it can also be used for initial production fields, the methodology was applied in a developed oil field and it was possible to show the advantages of the streamline simulation and quality map as support tools for numerical simulation.

Regarding the optimization methodology proposed in this paper, it can be said the following:

- The presented results demonstrate that this methodology is efficient to promote the increased production of oil and, in some scenarios, the decrease in water production, leading to increased oil recovery and NPV of the project;
- Despite the complexity inherent in the optimization process due to the high number of variables involved, this methodology showed good results, without having an excessive number of simulations;
- The use of the reservoir map quality and simulation streamlines allowed a faster and effective study of field production strategy, reducing the time of analysis in defining the changes that can be tested in the wells;
- The generation of the reservoir quality map shown useful to indicate the most suitable regions for new wells, making its location more precise and reliable process to complement the analysis of the field properties maps;
- The streamlines simulation proved to be a very important tool in the study of the behavior of fluid flow in the reservoir, allowing correlating the producing and the injector’s wells in the regions of the reservoir, making the management of the wells with high level of WCUT more efficient. With this type of simulation it was also possible to measure the efficiency of the injector’s wells, allowing the adjustment of the injection flow and the consequent increase in oil production and NPV of the field.
- The methodology applied in this study showed similar results in terms of NPV for various strategies studied with a different number of wells, demonstrating that the solution of the problem is not unique and there may be several strategies to achieve similar results.

7. References


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