Field Development Planning Optimization Using Reservoir Simulation

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Abstract

Field development planning comprises a great amount of investments and involves a high number of parameters related to the geological and structural characteristics of the reservoir, to the operational scheduling and the economic scenario. The importance of this problem demands the elaboration of methodologies that can help in the management decision making process, leading to better recovery strategies that increase both reserves and profitability of reservoirs.

This paper presents a methodology applied to the field development planning process. This methodology was elaborated concerning different types of reservoir and can be adapted to attend different geological characteristics and the operational constraints. It requires the use of reservoir simulation to obtain reliable predictions for production and injection performance that will be used in the optimization process.

Some examples were selected for the validation of the proposed methodology and the results are presented. It can be shown that this methodology is fast and requires a low number of simulation runs. It provides good quality solutions that will be analyzed by the management that will define a field development strategy according to the objectives of the project and the technical and financial resources available.

Introduction

Production strategy optimization has a great importance in the oil industry and must be applied to achieve different objectives. Sometimes, the main purpose of this process is to select an adequate production strategy to be applied in the reservoir development planning. In other instances, the objective is to utilize a detailed optimization procedure in order to obtain accurate results to support complex decisions. Another possible objective can be the optimization of mature fields in order to increase profitability or to adequate the production to a new economic scenario. The objectives are established by the management regarding the importance of the project and the technical and economic resources available and the decision making process must lead to lucrative results and high revenues, considering the physical and operational restrictions for each particular project. Hence, it is very important to develop new procedures to minimize risks and maximize profits in recovery strategy arrangements.

The use of reservoir simulation is very important to provide reliable production/injection forecast and correct predictions for field recovery potential. However, during the initial field development phase the amount of available information for the reservoir is very restricted and it is very difficult to obtain a correct reservoir model. Therefore, the use of simplified simulation models provides more appropriate and lead to better results.

This work proposes a methodology including a robust optimization procedure that uses the production/injection forecasts generated by reservoir simulation for the evaluation of an objective-function (NPV). This methodology helps in the decision making process granting a correct evaluation of relevant parameters in field recovery planning and it provides adequate solutions using a small number of simulation runs. Some examples based on different offshore fields were selected in order to validate the methodology and the results are presented. It can be shown the importance of reservoir simulation in field development planning to determine an adequate amount of producer and injector wells and propose a suitable scheduling. The procedure can be refined to increase the accuracy of the solutions and can also be adapted to define production strategies for field development under uncertainty. In this case different strategies are proposed for each geological model generated.

Literature Review

The planning of adequate recovery strategies for petroleum reservoirs has a great economic importance in oil industry and several studies have been performed in order to develop efficient procedures for this optimization problem.

Arps et alli [1967] participated of a study, organized by the American Petroleum Institute, with the objective of developing equations for the assessment of recovery factors for petroleum fields. The well spacing was one of the most
studied parameters. However, from the analysis of 312 different reservoirs they concluded that there was no mathematical relationship between recovery factor and well spacing. The purpose of their work was to develop a methodology for field recovery planning through an analysis preceding the stage involving simulation, but it was not possible to obtain satisfactory results.

Davis and Shepler [1969] verified that the well spacing initially used to develop a petroleum field, in general, isn’t the most adequate spacing. The ideal well spacing depends on characteristics of each reservoir. Thus being necessary to take into account the uncertainties related to the geological model and the dynamic behavior of the economic and technological scenario.

Reservoir simulation became an important tool for the development and management of petroleum reservoirs. Accurate reservoir performance predictions can be obtained through numerical simulation using a previously built geological model that comprises several parameters obtained through reservoir characterization. The simulation model is the most important tool for the evaluation of an objective-function that represents the global objective of the project.

Using numerical simulation, Nystad [1985], Damsleth et al [1992], Beckner and Song [1995] among others authors developed methods for optimization problems related to the development and management of petroleum reservoirs. These works presented the following common features: They required some previously established simplifications and the number of simulations runs performed and evaluated parameters was small. The objectives of such works were the evaluation of the most important parameters in the assessment of the objective-function and their optimization.

Bittencourt [1997] developed a hybrid algorithm based on direct methods, like genetic algorithm, Polytope method and Tabu Search, for optimization problems related to petroleum field development. The simulator was used as a data generator for the evaluation of the objective function, which involved an analysis of cash flows resulting from production predictions obtained from reservoir simulation.

Pedroso and Schiozer [2000] developed a methodology for the optimization of the number of producer wells and their location in a reservoir in development stage.

Cruz [1999] introduced the concept of “quality map”, which is a bi-dimensional representation for reservoir performance and its uncertainties, mainly related to the geological model. This concept can be applied to compare reservoirs, to classify stochastic realizations and to include geological uncertainties in the decision making process for recovery strategy planning.

Mezzomo and Schiozer [2000] developed a procedure for primary recovery strategies optimization, comprising only vertical producer wells. In order to expand the scope of that procedure, compassing a greater number of reservoirs, this work developed a more flexible and adaptable methodology, including water injection with producer and injector vertical and horizontal wells.

**Methodology**

In order to develop a methodology to the optimization problem of recovery strategy planning for different reservoirs, it is necessary to evaluate several parameters mainly related to the geological model, operational conditions and economic scenario.

The objective of this work is to present a new methodology to support managers in the decision making process for water injection planning optimization for fields in development stage and under operational and economic restrictions.

**Methodology Description**

The general methodology proposed in this work is organized in several steps that are presented in Figure 1 and will be described in the following paragraphs.

Depending on the objectives defined for the project and the time available to the decision making process, some of these steps can be simplified or discarded.

**Step 1: Recovery Strategy Assessment**

In this first step, a study based on field data is performed for the assessment of relevant geological and physical reservoir parameter, that will be used for the definition of basic important parameters related to recovery strategy like well type (producer or injector) and geometry (vertical, horizontal or deviated). This study will also evaluate the necessity of a secondary recovery (water and/or gas injection) or an enhanced recovery method (thermal, chemical, etc).
Step 2: Production/injection Patterns Evaluation

The second step comprises an evaluation of several production/injection patterns proposed according to the recovery method and the well type and geometry established in the previous step. The production/injection patterns are defined based on field characteristics, the technical and financial resources available.

During this stage, simulation runs are performed to assess the recovery potential for each pattern proposed for the field. At this stage, all wells comprised by the defined patterns must be opened simultaneously at the initial time of the simulation runs in order to obtain a correct evaluation of their production/injection performance. The best patterns are retained and submitted to the optimization procedure in the next step.

Step 3: Estimation of the Approximate Number of Wells

As stated before, the patterns retained in the previous stage are then submitted to an optimization procedure. The optimization procedure will provide the ideal number of wells for these selected recovery patterns, and it must take into account the relevant reservoir parameters, the number of required simulation runs, and the desired quality for the results.

As in the previous stage, throughout this optimization procedure, all wells must start to produce/inject simultaneously in order to obtain a correct evaluation of the potential of each well and an accurate value for their objective-function. This optimization procedure must be adapted to attend the operational and economic restrictions imposed on the project. Figure 2 presents a flowchart that summarizes this optimization procedure.

Step 4: Obligatory Optimization

The optimization process is always restricted to operational restrictions that are mainly defined by the investments and costs established for the project. These conditions always lead to a mandatory optimization, and this stage defines important parameters, like well scheduling, in order to present feasible solutions that can lead to good results.

The conditions applied to this obligatory optimization may be proposed according to the characteristics of the project and the available technical resources.

Step 5: Economic Sensitivity Analysis

The economic scenario presents a very dynamic behavior and is strongly influenced by technical and political circumstances. Therefore, parameters like oil price tend to show significant variations throughout the project life.

An economic sensitivity analysis is very important for a recovery strategy planning. The use of reservoir simulation allows an accurate evaluation of the potential of each alternative comprised in the set of recovery patterns presented by the methodology regarding different feasible economic scenarios, and the objective at this stage of the...
methodology is to identify the alternatives that present low financial risk and that are less influenced by economic scenario alterations.

**Initialization: Assessment of the Initial Well Spacing for the Selected Patterns**

**Simulation Run**

**Objective-function Evaluation – Producer/Injector wells Ranking**

**Determination of the new total number of wells**

**Total NPV increases ?**

**End**

**Fig. 2: Optimization Algorithm**

**Case Study**

Two examples were proposed for the validation of this methodology, based of offshore fields. The first one presented a solution gas drive mechanism and the second one comprised a strong bottom aquifer. Considering that they were on initial development stage, the simulation models used were simple due to the restricted amount of geological and physical data available. They comprised a black-oil system containing three phases: oil, gas and water.

On important aspect of this work is that it is not necessary to perform all the simulation runs executed. They were performed to validate the methodology.

**Results**

**Selection of the Objective-Function**

The net present value (NPV) was defined as the objective-function to be maximized. Two other indicators, cumulative oil production (Np) and rate of return (RR), defined as NPV/investment, were also analyzed for a more adequate evaluation of the set of alternatives of water injection patterns. The objective was to identify from graphs, strategies that allow the simultaneous maximization of oil production, return coefficient and Net Present Value for the two selected reservoirs.

**Step 1:**

Considering that the purpose of this work that was to develop a methodology for optimization of recovery strategies including water injection, it was assumed that a geological study indicated recovery strategies comprising vertical producer and injector wells.

**Step 2:**

The water injection patterns evaluated in for the two reservoirs selected for the study case were the most frequently used for secondary recovery of offshore fields: peripheral (with different ratios between producer and injector wells), five-spot (5spot), seven spot (7spot), nine spot (9spot), direct linedrive, alternate and combined. The recovery performance and the values obtained for the objective-function and for the rate of return for the first reservoir are presented in Figures 3, 4, 5 and 6. The same graphs are presented for the second reservoir in Figures 7, 8, 9 and 10.
Fig 3: Case A – Step 2 – NPV vs ratio between producer and injector wells

Fig 4: Case A: Step 2 – NPV vs Cumulative Oil Production

Fig 5: Case A: Step 2 – NPV vs Rate of Return

Fig 6: Case A – Step 2 – NPV vs ratio between Cumulative Produced Water and Cumulative Injected Water

Fig 7: Case B: Step 2 – NPV vs Cumulative Oil Production

Fig 8: Case B: Step 2 – NPV vs Cumulative Oil Production
These figures indicate the efficiency of the injection patterns for the selected field, with different well spacing and they also allow the comparison of objective-function values obtained with their application. This is very important in the decision making process for the planning of a recovery strategy.

From these graphs it can be shown that for both reservoirs, the most efficient patterns presented a ratio between producer and injector wells close to 1. The initial well spacing of 450m provided the highest values for cumulative oil production and NPV while the well spacing of 600m provided the best values for the rate of return.

**Step 3:**

The best patterns with the initial well spacing of 450m for both reservoirs were submitted to the optimization algorithm for the assessment of an estimative of the total number of producer and injector wells.

It was necessary to perform 8 simulations runs to estimate the amount of wells for each of these selected patterns. It is also important to observe that the objective-function, due to its characteristics of non-linearity, presents local optimal values.

The results obtained throughout this step for the selected patterns of both reservoirs are presented in Figures 11, 12, 13 and 14. It can be noted a reduction in the cumulative oil production and a significant increase in the objective-function values.

This optimization procedure is simple and fast. The quality of the results are mostly affected by the initial well spacing previously defined and on the criteria applied to the wells during the simulation runs performed to achieve a good estimate for the number of wells.
Step 4:

This step was performed for the assessment of an ideal well scheduling for the water injection patterns optimized in the previous stage using reservoir simulation and considering the production and injection performance presented by the well.

Three well scheduling were proposed for the selected patterns, with an interval of 2 months according to the established operational constraints.

Figures 15 and 16 indicate the results obtained for the objective-function and for the cumulative oil production (Np) for each of the selected schemes.

Step 5:

Considering the objective of this work and the type of recovery method planned for both reservoirs, it was assumed that the results obtained after applying the four previous steps were satisfactory and it was not required the application of Step 5.

Discussion

The methodology and the optimization procedure presented a low computational cost and provided good quality solutions for both reservoirs studied in this work. It allowed a proper evaluation of the objective-function behavior for the different alternatives proposed for recovery strategy with water injection using vertical wells and in order to achieve this it is very important to define carefully the constraints for the optimization procedure and to execute an individual analysis for the behavior of each well throughout the simulation runs performed in steps 3 and 4.

The procedure can be easily automated in order to reduce the global time required for the process. However, at the end of the procedure, it is necessary to execute a manual analysis of each well performance to account for details that may be not evaluated by the automatic procedure.
Conclusions

1. The methodology developed in this work is adequate to help in the decision making process for recovery strategy planning including oil production and water injection. It provides a set of good alternatives that must be analyzed regarding the objectives and the resources available previously defined for the project.

2. The methodology is flexible and presents a low computational cost. Depending on the characteristics of the project some steps can be simplified or discarded.

3. Steps 3 and 4 must be adapted to attend the different characteristics of each natural drive and recovery method. It is necessary to account for the constraints associated to each project for the obligatory optimization.

4. For the examples studied in this work, the well spacing and the well scheduling were parameters that strongly affected the results generated by the methodology.

5. The best water injection patterns for the reservoirs studied in this work presented a ratio between producer and injector wells close to 1.

6. In the procedure used in this work, as the steps are executed, production strategies alternatives are eliminated and the number of required simulations runs is reduced. At the end of the procedure, a manual analysis of each well performance is recommended to account for details that may be not evaluated by the automatic procedure.

References


