Year 11, Number 7
103rd edition
August, 2016

UNISIM ON-LINE

Production Strategy Selection for Water and Polymer Flooding in Heavy Oil Field Development

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Introduction

Polymer flooding is a chemical EOR technique in which polymer is added to injection water, increasing its viscosity, decreasing water-oil mobility ratio and improving sweep efficiency. This recovery method create unique conditions that are absent in traditional water flooding, which makes an adequate production strategy essential to the success of the project. This text is based on the paper SPE 180838 (Botechia *et al.*, 2016), presenting a methodology for production strategy selection, considering water and polymer flooding for comparison purposes. This work is part of a comprehensive decision analysis methodology (Schiozer *et al.*, 2015), but here is presented only Step 6, regarding to the production strategy selection of the base case. The main focus here is to show the importance of applying a robust process separately for water and polymer flooding, otherwise wrong decisions can be made if simple comparisons are performed.

Methodology

The process aims the maximization of NPV. We chose this objective-function because it is a proper tool to compare water and polymer flooding, since it takes into account the production of oil and water, speed of recovery and the cost for polymer injection. However, the methodology allows the use of other indicators, such as cumulative oil production or recovery factor, but it is necessary to take care when using only a technical indicator as objective function. Polymer injection may result in increased oil production, but it has to be considered that there is an additional investment (cost) for that incremental oil to be produced.

The methodology is applied separately for water and polymer flooding, so that a proper comparison between these two mechanisms can be made. The optimization is divided in seven main steps, listed below.

- **Step 6.1**: Number and location of wells
  - Step 6.1.1: Definition of a base scheme
  - Step 6.1.2: Removal of wells with poor performance
  - Step 6.1.3: Addition of wells in the model
  - Step 6.1.4: Optimization of well location
- **Step 6.2**: Production system capabilities
- **Step 6.3**: Schedule of well drilling
- **Step 6.4**: Production/injection well rates and BHP
- **Step 6.5**: Economic water cut limit for well shutdown
- **Step 6.6**: Concentration (for polymer flooding only)
- **Step 6.7**: Slug size (for polymer flooding only)

Steps 6.1 to 6.3 relate to project variables (G1), which cannot be altered after strategy implementation, while Steps 6.4 to 6.7 relate to operational variables (G2), and regards to the management of the field, hence it is possible to change these variables after strategy implementation. Moreover, Steps 6.6 and 6.7 regards to polymer specificities, thus they are applied only for polymer flooding.

When the process is finished, there are two production strategies to be compared, one for water flooding and other one for polymer flooding. One additional step of the methodology is to perform the **crossed simulations**, which means injecting water in polymer flooding strategy and injecting polymer in water flooding strategy. In this case, G2 variables must be optimized again. The objectives of this extra step are to confirm if the strategies are adequate and to verify if there is flexibility to change the injection fluid without losing the profitability of the project.

Application

The model used in this work is representative of offshore heavy oil field, which has regions with high permeability rocks among others with very low permeability. The oil is 15° API and 174 cP. The model grid has a total of 106,080 cells (104 x 102 x 10) with 100 x 100m length and variable thickness. Figure 1 shows the 3-D view of the horizontal permeability map in logarithmic scale.

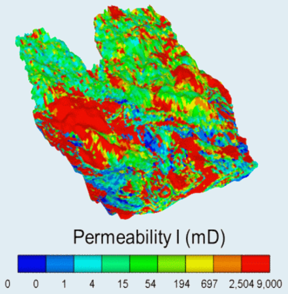

Figure 1: *3D view of horizontal permeability in logarithmic scale.*

Results

In the end of the optimization process, two strategies were obtained, one for water flooding, with 16 wells (14 prod. and 2 inj.), and another one for polymer flooding, with 17 wells (13 prod. and 4 inj.). Besides similar strategies, polymer flooding strategy has more injectors due to the lower injectivity caused by the high viscosity solution injection. In Figure 2, the red line represents the injection rate for polymer flooding strategy and the blue line for water flooding strategy. It is noticeable the start of the polymer bank (mid-2014, when the injectivity decreases due to higher solution injection viscosity) and the end of it (2035) when there is a sudden increase in injection, since water is injected again, with lower viscosity than polymer solution.

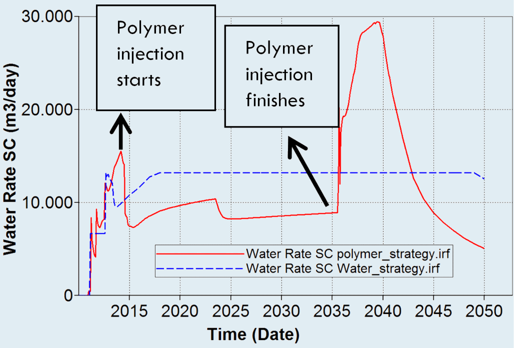

Figure 2: *Injection rate for polymer flooding (red line) and water flooding (blue line) strategies.*

It is observed great improvement in economic and technical indicators for optimized strategies in relation to initial ones (Figure 3 and Figure 4). Moreover, polymer flooding showed to be a feasible alternative to recovery this heavy oil field, presenting better economic efficiency than water flooding, due to higher oil production and to the reduction of the produced water. For optimized polymer flooding strategy, NPV was 7% higher than water flooding strategy, while oil produced was 8% higher and there was a reduction of 30% in produced water.

Figure 5 shows the results for the crossed simulations, presenting NPV evolution over time with G2 variables not optimized (Figure 5a) and after their optimization (Figure 5b). The following nomenclature for the graphics was adopted: the first letter wounds to the strategy that the field has been optimized, and the second one refers to the injected fluid. Thus, WW means water

> *"Polymer flooding create unique conditions that are absent in traditional water flooding, which makes the decision analysis process essential to the success of the project."*

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> *"Simple comparisons, such as injecting polymer in a strategy prepared for water injection, may yield wrong decisions."*

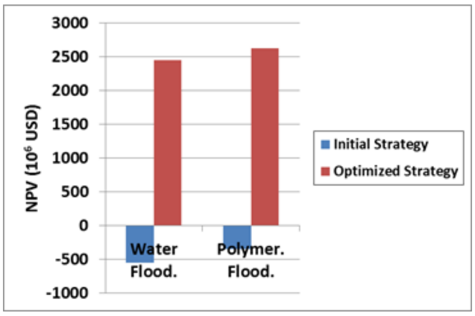


Figure 3: *NPV for water and polymer flooding strategies, in the beginning and in the end of optimization process.*

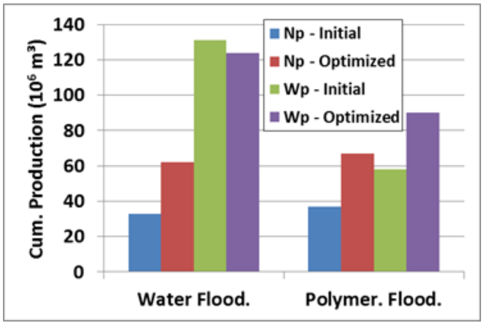


Figure 4: *Cumulative productions (oil and water) for water and polymer flooding strategies, in the beginning and in the end of optimization process.*

injection in the optimized water strategy, PP means polymer injection in polymer strategy, PW means water injection in the polymer strategy and WP is polymer injection in the water strategy.

The execution of these crossed simulations shows the importance of applying the steps of the optimization process separately for water and polymer flooding, since it is obtained strategies more adequate for the fluid that it is being injected and more accurate comparisons can be made. If this comparison is made in a simplified manner (for example, just by changing the injection fluid) a wrong decision can be made. For example, when injecting polymer in a strategy prepared for water injection (purple curve – WP in Figure 5) this alternative may seem inadequate when compared with water flooding (blue curve – WW). However, if the selection of the production strategy considers polymer flooding in early field development, this alternative is the best option (red curve – PP).

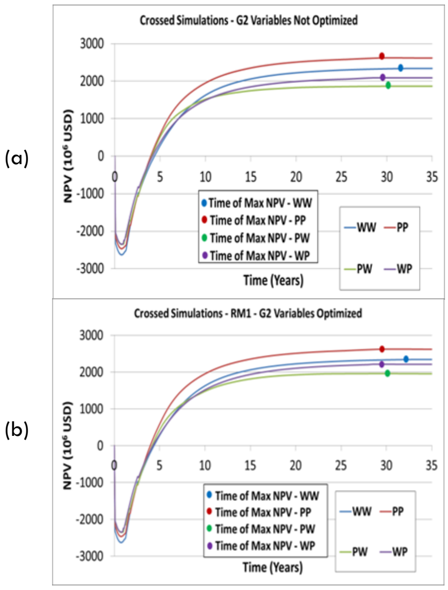
Therefore, the ideal procedure would be taking into account the fluid that is going to be injected early in the development of the field, hence obtaining the best possible efficiency in the project. However, if the injection fluid is altered, it is necessary to optimize operational variables to be more suitable to the new injection fluid, which gives more flexibility to do this alteration. This fact can be noted in Figure 5b, where the purple curve is closest to the blue one than in Figure 5a, in which the operational variables were not optimized.

Conclusions

We presented a procedure to production strategy selection comparing polymer and water flooding for heavy oil field development. This process is part of a complete decision analysis, which will be performed in further works, with a probabilistic approach.

For the studied case, polymer flooding showed to be a feasible alternative. The high level of water produced in water flooding (due to the presence of the heavy oil) was significantly decreased when injecting polymer. Moreover, higher level of oil production was obtained with polymer flooding and all these facts resulted in best economic efficiency for this recovery mechanism, even with higher investments that was necessary to be made.

It was demonstrated the importance of following separately the process for water and polymer flooding in order to make an appropriate comparison between these two methods. Simple comparisons, such as injecting polymer in a strategy prepared for water injection, may lead to wrong decisions, since polymer may seem not adequate if a simple procedure like that is made. The best option would be take into account the fluid that is going to be injected early in the development of the field, reaching the best efficiency for the project. However, it is possible to make some alterations, since the operational variables are also changed to be most suitable to the new injection fluid.


(a)

Crossed Simulations - G2 Variables Not Optimized

(b)

Crossed Simulations - RM1 - G2 Variables Optimized

Figure 5: *NPV evolution over time for the crossed simulations with G2 variables (a) not optimized and (b) optimized.*

Acknowledgments

We would like to thank UNISIM, DE-FEM, CEPETRO, PETROBRAS, STATOIL, FCMG and ANP for supporting this work. We also thank CMG for software licenses.

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