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Decision Analysis comparing Water and Polymer Flooding under Uncertainties in Heavy Oil Field

Vinícius Eduardo Botechia

"Comparing polymer flooding with other recovery methods is a complex task and should involve in-depth procedures to reduce the chance of ill informed decisions."

Introduction

Decision analysis is an effective tool to guide decision through an evaluation of alternative strategies. Uncertainty is inherent in many decision-making processes. Including the possibility of loss, resources and information are used to minimize this possibility. When using more advanced technology, such as polymer flooding, the complexity and number of uncertain variables are even higher, with several phenomena related to polymer flooding that are absent in water flooding, such as adsorption and non-Newtonian behavior.

Thus, comparing this enhanced technique with other recovery methods and deciding whether to use polymer flooding are complex tasks and should involve in-depth procedures to reduce the chance of ill informed decisions.

The purpose of this text is to show a methodology to guide the selection, of the best strategy option using comparisons between water and polymer flooding projects in a heavy oil field development, under uncertainty, through a risk-return analysis.

Methodology

The methodology is based on the 12-step decision analysis methodology presented by Schiozer *et al.* (2015) summarized below. This text focuses on Steps 7 to 12.

1. Reservoir characterization considering uncertainties.
2. Construction and calibration of the base model.
3. Verification of inconsistencies in base model with well data.
4. Generation of scenarios - risk curve.
5. Reduction of scenarios using dynamic data.
6. Selection of deterministic production strategy for the base model.
7. Quantification of initial risk (base model strategy).
8. Selection of Representative Models (RM).
9. Production strategy selection for each RM.
10. Selection of production strategy under uncertainty including economic and other uncertainties.
11. Identification of potential for: strategy changes, new information (VDI) or flexibility (VDF), tests and strategy choice.
12. Final risk curve.

In Step 7, we generate initial risk curves using the optimized production strategies presented in previous works (Botechia et al., 2016). It is considered different risk curves for water and polymer flooding. To generate the risk curves, we create uncertain scenarios by combining geological uncertainties using probabilities distributions and statistical techniques. Each simulation model represents one uncertain scenario.

Based on the initial risk curves and cross plots that correlate several indicators (such as NPV, Np, Wp and recovery factor), in Step 8 we select some representative models (RM). These RM aims to represent the variability of the uncertainties in a small number of models. First, we generate the cross plots and risk curves for water flooding, and choose models that represent a great variability of the selected indicators. We then do the same for polymer flooding and check if the chosen models are still representative for the polymer flooding case. If not, more models need to be selected.

In Step 9, the production strategy is optimized for all RM. Thus, for each RM, there are two production strategies, one considering water flooding and other one for polymer flooding. This step also includes the crossed simulations, which means injecting water in polymer flooding strategy and injecting polymer in water flooding strategy.

In Step 10, the strategies from the RM optimization are resubmitted to numerical simulation for all models that represent uncertain scenarios. Thus, each production strategy has an associated risk curve.

Step 11 is not performed since involves complex analysis and will be addressed in future works.

Finally, in Step 12, we perform a risk-return analysis plotting the risk for each strategy against the return. We measure economic return by Expected Monetary Value (EMV), defined as the sum of the Net Present Values (NPV) of the considered scenarios, weighted by their respective probabilities of occurrence. We use semi deviation to define risk (Santos, 2015). This risk measure defines risk as exposure to loss, not a global dispersion, like the most commonly used standard deviation. Thus, semi deviation measures the probability and magnitude of losses through a benchmark value, as shown in Equation 1, where b is the point in the distribution below which losses are considered. In this work, the best EMV is considered as the reference value. We measure the risk of returns lower than this value, while higher returns are considered risk-free.

$$\mathrm{Sb} = \sqrt{\frac{1}{N}\sum_{Xi<b}(Xi-b)^2} \qquad \textit{Equation 1}$$

Application

The base 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.

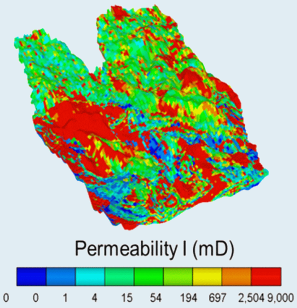

***Figure 1:** 3D view of horizontal permeability in logarithmic scale*

Results

Based on the initial risk curve, we chose 9 RM (red dots in Figure 2), which means that 18 productions strategies were available (9 for water flooding and 9 for polymer flooding). The points that are inside the squares represent the base model (RM1) and P50 model (RM5).

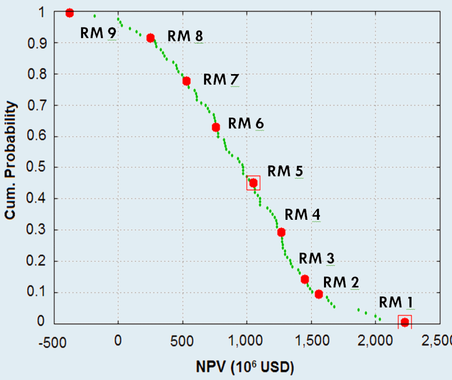

***Figure 2:** Injection rate for polymer flooding (red line) and water flooding (blue line) strategies.*

Figure 3 shows the NPV results for crossed simulations of the strategies from the representative models. This graph uses the strategy number according to the RM for which it was optimized, the last letter indicating the fluid. For example, strategy S1W is obtained from RM1 considering water injection, S2P is the strategy obtained from RM2 considering polymer injection and so on. The nomenclatures WW and PP represent the strategies optimized for water and polymer flooding, respectively. WP stands for optimized strategy for water injection, but injecting polymer, while PW is polymer strategy, but injecting water. The results are shown before and after optimization of operational (G2) variables in the crossed simulations. These variables can be changed after the strategy is implemented, since they are related to the management of the field.

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"If polymer flooding is being considered for use in the development of a field, a detailed evaluation is fundamental."

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In Figure 3, we can see the significant deterioration in the economic performance of the strategy for all analyzed cases when the injection fluid is changed. Part of this loss can be minimized by optimizing the operational variables. For WP cases, it is not shown the optimization of G2 variables because the best option would be decreasing the amount of polymer to zero, which is the same that injecting water.

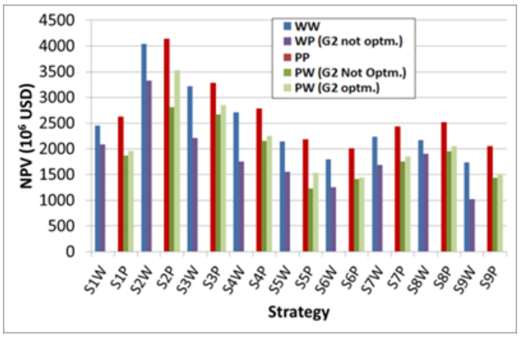

Figure 3: *NPV for water and polymer flooding strategies for all representative models, including crossed simulations.*

Figure 4 shows the risk vs return graph, where the blue points represent water-flooding strategies and red points, polymer-flooding strategies. To calculate risk, we used the best EMV (1.8 USD Billion for S8P) as the reference value and considered the risk of returns lower than this.

Moreover, for the best strategies (S8P for polymer and S3W for water), we tested the performance of these strategies when the injection fluid is altered (injecting water in S8P and injecting polymer in S3W). It is noticeable a significant loss of performance in the strategies when making this alteration. In the graph below, the longer arrow indicates the loss of economic efficiency by injecting polymers in S3W strategy, while the shorter arrow indicates the loss when changing polymer to water in S8P strategy.

The higher loss of efficiency happened when exchanging polymer into water in S3W strategy, so that this became the worst strategy for this situation. When changing polymer for water in S8P strategy, the loss of efficiency was not as great. However, the loss was further reduced for optimized G2 (operational) variables where water is exchanged to polymer. This is because more operational variables were optimized in this case, such as polymer solution concentration and polymer bank size.

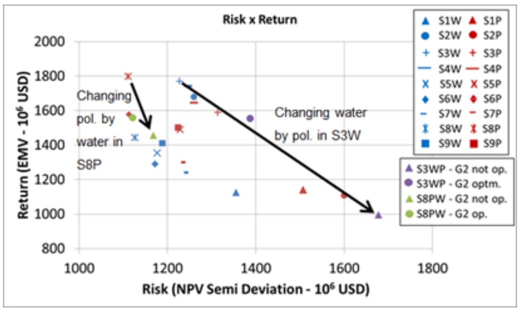

Figure 4: *Risk-return graph including crossed simulations for S8P and S3W. S8PW representes the best strategy for polymer flooding, but injecting water, while S3WP representes the best strategy for water flooding, but injecting polymers.*

Figure 5 shows the risk curves for all strategies, and the following curves are highlighted: S1W (base case strategy for water flooding), S1P (base case strategy for polymer flooding), S3W (best return for water flooding) and S8P (best return for polymer flooding). The black bar indicates the reference EMV for risk calculation. The final risk curves (S3W and S8P) are very different from the initial estimated risk curves (S1W and S1P), further demonstrating the importance of a complete risk analysis procedure, as the level of risk was greatly reduced. The high risk and the chance of about 15% of negatives values give opportunities to further studies in Step 11 but are not shown in this work.

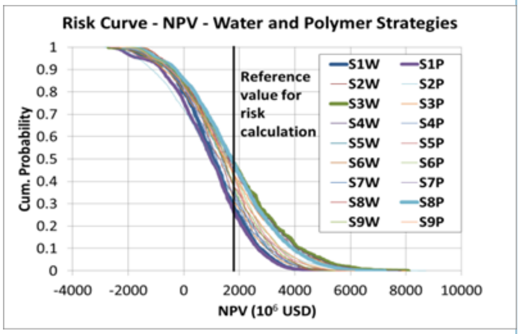

Figure 5: *NPV evolution over time for the crossed simulations with G2 variables (a) not optimized and (b) optimized.*

Conclusions

We presented an application of a comprehensive procedure for risk assessment and decision analysis involving enhanced oil recovery (polymer flooding) in comparison with water flooding.

We showed that simplified comparisons, only exchanging water by polymer, can lead to poor economic performance and sub-optimal decisions. Comparing water and polymer flooding is complex and a detailed evaluation is fundamental. Processes involving several steps for each recovery mechanism are necessary to increase the chances of success in the final decision-making process taking advantage of the higher investments and costs necessary with polymer flooding.

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About author: Vinícius Eduardo Botechia holds an electrical engineering from UNESP, a M.S. and PhD degrees in Petroleum Science and Engineering from UNICAMP. He is researcher at UNISIM since 2013 working on decision analysis, production strategy optimization and polymer flooding.

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Petroleum Engineering Division - Energy Department
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Phone: 55-19-3521-1220
Fax: 55-19-3289-4916

unisim@cepetro.unicamp.br