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# Fast Simulation Models Applied to Polymer Flooding in Heterogeneous Reservoirs

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> *"Reservoir characterization became more detailed due to advances of geostatistical methods. If in one hand the models are more reliable, on the other hand the simulation time has increased considerably."*

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## Introduction

The comparison between techniques for enhanced oil recovery requires accuracy of the simulation models to ensure the reliability of the study. The analysis of relevant data, including uncertainties, aims to improve the decision-making process and requires a large amount of simulation runs. Due to high simulation time generated by the detailing of reservoir models given by recent improvement of geostatistical techniques, engineers demand methods to create fast models. The goal is to maintain the reliability, especially for cases using complex reservoirs.

The development of fast simulation models to represent a region or wells of interest of the reservoir is common practice in the oil industry and fast simulation models (FSM) or proxies can be used to reduce simulation time (Bordeaux-Rego, 2016). The motivation of this work was the need to compare the feasibility of water and polymer flooding to recover a heavy oil heterogeneous reservoir. Due to the high simulation time of the base model, there was a need to generate FSM to enhance decision making without losing reliability of production results for a region of interest.

## Methodology

The methodology to test the reduction of simulation time for a region of interest is separated into two steps: construction of FSM and evaluation if the FSM is in accordance with the reference model.

***1) Construction of FSM***

**1.1) Evaluation of the reference model (Base) and the region of interest:** The Base model must have the best existing characterization, with geological properties (e.g. heterogeneities) modeled with the highest possible refinement. Those refined models almost always lead to high simulation time. For a simulation model be a candidate for application of the proposed methodology, it must have two main characteristics: present high computational time and contain a region or wells of interest. The choice of the region of interest is based on study objective: to evaluate the behavior of a complex area; the interdependence relationship between nearby wells; or to compare important aspects of a given injection method.

**1.2) Optimization and selection of the production strategy (OTM):** The selection of a production strategy for the Base model from an optimization process is used as a reference for comparison with the methods for reducing simulation time (fast models). The optimization methodology was based on Botechia et al. (2016) and uses net present value (NPV) maximization. If the Base model has a pre-established production strategy with previously drilled wells (e.g. mature fields), this step of the methodology does not need to be performed.

**1.3) Model generation to reduce simulation time (FSM):** Two techniques for creating the FSM are used and compared: drainage area (DA) and upscaling (UP).

***DA FSM***: Cut the model around wells of interest using the oil and water streamlines to guide the drainage area region. At this step, the visualization of the streamlines on reservoir map can be extremely helpful.

***UP FSM***: Generate upscaled model from the base model producing a coarser grid. The upscaling method can vary from different users but it needs to take into account that the simulation time is closer to drainage area model and not too complex to perform.

***2) Evaluation of the FSM:*** Define which model is best appropriate to represent a particular region (or wells) of interest. The analysis is based on the relation of the decrease of simulation time and maintenance of reliability of the production results in comparison to the reference model (OTM Strategy). The Normalized Quadratic Distance with Signal (NQDS) is used to compare the various production indicators of the wells of interest over time (Avansi, 2014). This is a useful tool that quantifies whether the curve is adjusted relative to a reference curve. If NQDS index is between -1 and 1, the analyzed data sequence is considered adjusted to the reference data.

$$NQDS = \frac{\sum_{i=1}^{n}(ref_i \times sim_i)^2}{\sum_{i=1}^{n}(ref_i \times \gamma)^2} \qquad \text{Equation 1}$$

## Application

The reference model (Base) used to apply this methodology is a heavy oil (174 cP and 15°API) and high heterogeneous offshore field with high permeability zones among other with low permeability. The Base model is a corner point grid with 103 x 102 blocks in i and j direction (100 meters width) each and 188 blocks on k with an average reservoir thickness of 30 meters (vertically refined). The model has approximately 207,000 active blocks and three perforated wells (P01, P02 and I01) with no production history, as shown in Figure 1.

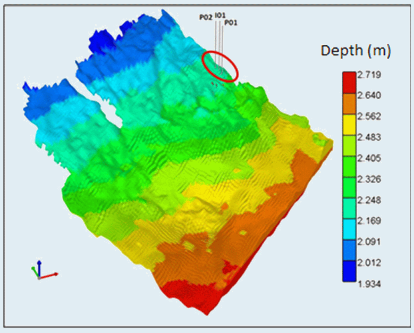

***Figure 1:*** *Base model highlighted the three wells of interest (P01, P02 and I01).*

## Results

The results are divided into items according to the methodology.

**1.1)** The reference model (Base) presents three drilled wells (P01, P02 and I01) as shown in Figure 1. These wells are used as reference for the comparison of the production results, i.e., the wells of interest. Due to high permeability stratifications combined with heavy oil, the water injection breakthrough happens too fast, making this region a good candidate for polymer flooding (mobility control). The simulation time of this model is 75 minutes, which is considered high for only three wells operating for 30 years.

**1.2)** The final strategy production after optimization (OTM) presents 21 wells (18 producers and 03 injectors) for water and 22 wells (13 producers and 05 injectors) for polymer flooding. The NPV value for polymer injection is 5% higher than water flooding. The production results of wells of interest with (OTM) and without (Base) production strategy are very different, with liquid production being overestimated when there is no well interference.

**1.3) *DA FSM:*** To determine which wells influence the liquid drainage of the wells of interest, the analysis of the flow lines becomes fundamental. When cutting the model, it should not be done in areas where the flow lines are in higher density, especially those that are directly connected to the wells of interest (in this case, the wells P01, P02 and I01). Neighbor wells should not be neglected in the region of interest because they provide influence on the drainage of wells within the region of interest. Figure 2 shows the DA FSM for water (left) and polymer (right) flooding.

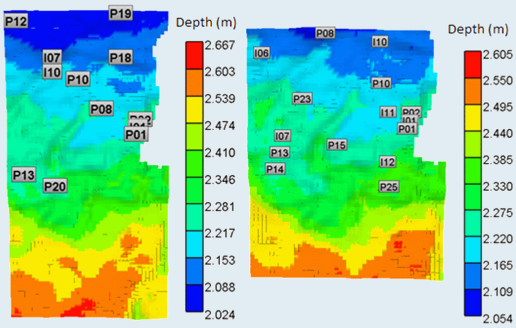

***Figure 2:*** *Water (left) and polymer (right) DA FSM.*

***UP FSM:*** The upscaling of the properties of the refined model is carried out only in the k direction, since it is considered much more refined than in i and j directions. The number of blocks was reduced from 188 to 10, keeping the same 30 meters of reservoir thickness. The positions of the UP FSM wells are carefully adapted so that there are minimal spatial variations in relation to the optimized model (OTM). Figure 3 shows an example of the comparison between refined model and UP FSM in k direction.

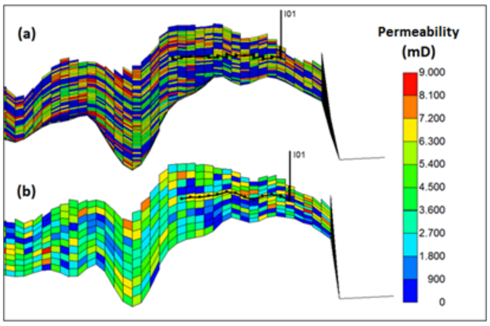

***Figure 3:*** *Base model (a) and UP FSM (b) comparison in k direction.*

***2)*** Figure 4 shows the relationship of the NQDS results for each production indicator used for DA and UP FSM for water and polymer flooding in comparison to OTM. The red lines in the graph indicate the tolerances of NQDS indicators. Table 1 shows the comparison of simulation time and number of blocks for OTM, DA and UP FSMs.

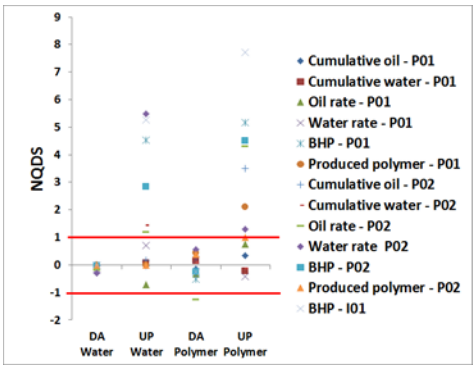

***Figure 4:*** *NQDS of DA and UP FSM for water and polymer flooding*

***Table 1:*** *Simulation time and active blocks of Base, DA and UP FSMs*

| Model | Simulation Time (min) | Active blocks |
|---|---|---|
| OTM Water | 187 | 207,000 |
| OTM Polymer | 189 | |
| DA Water | 51 | 104,000 |
| DA Polymer | 61 | 90,000 |
| UP Water | 70 | 91,000 |
| UP Polymer | 72 | |

From Figure 4 we can note that the absolute NQDS averages demonstrate that the DA FSM has a better precision of the production results for the wells of interest compared to the UP FSM. The mean NQDS indicator variation was between 0.09 and 0.41 for AD and 1.71 and 3.9 for UP. In addition, it can be verified that there is a clear correlation between the number of blocks of the models tested and the simulation time. The reduction in simulation time for these FSMs can be considered similar, being on average 65% of the time in relation to the base model with OTM strategy (average reduction of 67% for DA and 63% for UP).

## Conclusion

The drainage area FSM (DA) was more adequate to represent the wells of interest in comparison to upscaled FSM (UP) with the objective of keeping reliability of production results and decrease simulation time.

For the upscaling technique used, there is clear evidence that the flow in porous media was affected by changes in block size by homogenization of the rock properties within them. As drainage area method does not change the block size, this problem is less pronounced.

However, for an adequate representation of the drainage area of a region of interest, it is recommended to:

- Consider the influence of neighboring wells on the production strategy;
- Not cut regions where the density of flow lines are larger so as not to compromise production results; and
- Evaluate the injection method applied to estimate if the differences between mobility ratios (and consequently different sweeping efficiencies) can generate drainage areas different other than water flooding.

## Acknowledgments

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## References

AVANSI, G. D. “Ajuste de Histórico Integrado à Caracterização de Reservatórios de Petróleo e Sísmica 4D”. p.246. Doctorate Thesis, University of Campinas: 2014. Available in goo.gl/L5iPlr.

BORDEAUX-REGO, F.; BOTECHIA, V. E.; CORREIA, M.; SCHIOZER, D. J. “Quantifying the Impact of Grid Size to Compare Water and Polymer Flooding Strategies in a Highly Heterogeneous Offshore Field”. Brazilian Journal of Petroleum and Gas. v. 10, p. 63–76: 2016. Available in http://dx.doi.org/10.5419/bjpg2016-0006.

BOTECHIA, V. E.; CORREIA, M. G.; SCHIOZER, D. J. A “Model-based Production Strategy Selection Considering Polymer Flooding in Heavy Oil Field Development. SPE Energy Resources Conference”. Port of Spain, Trinidad and Tobago: 2016. Available in goo.gl/Hwtr97.

## About author

Fabio Bordeaux Rego holds BSc in Chemical Engineering and MSc in Petroleum Science and Engineering from UNICAMP. He is a researcher at UNISIM working on production strategy optimization for polymer flooding technical and economic feasibility.

> *“The drainage area (DA) technique was more adequate to represent the wells of interest in comparison to upscaling technique (UP).”*

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