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Analysis of history matching and production forecast using a theoretical reservoir model

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Introduction

The ultimate goal of history matching is to improve the predictive capacity of reservoir models. However, finding the best matched models may not ensure reliable forecasts. This is shown in this text through a very simple, but interesting, theoretical reservoir model.

Model description

The theoretical reservoir is represented by a cross-section vertical model composed of three layers with 20 cells in the x direction (Figure 1). The permeability of the first layer was fixed in 1000 mD and for the other two layers (2 and 3), the value of the permeability is uncertain varying between 200 mD and 2500 mD. The pair of values [Kx2, Kx3] = [600, 2000] was chosen to compose the reference model. There is one injector in one extremity and one producer in another. This model could represent, for example, a super-k system in a real reservoir. The reference model was run in prediction mode to generate a synthetic history (1350 days), being the producer controlled by a maximum liquid rate (QLmax) of 80 m^3/d and minimum bottom-hole pressure (BHP) of 15000 kPa and the injector controlled by a maximum water rate (Qwi) of 80 m^3/d and 45000 kPa.

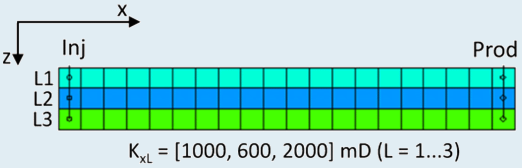

Figure 1: *Reference (true) model.*

Quality match

The quality match is measured by the Normalized Quadratic Distance with Signal (NQDS), which represents an acceptable misfit based on a tolerance applied to the observed data. More details can be found in Maschio and Schiozer (2016). For Prod_Qo and Inj_Qw, a tolerance (Tol) of 0.05 was used and for the others, Tol was set to 0.1.

Exhaustive sampling

To scan the entire search space under a high resolution, the ranges of Kx2 and Kx3 were divided into 100 equally spaced values and combined to form a grid with 10000 combinations. Figure 2 shows, in gray, all combinations and, in green, the combinations with |NQDS|<1 for all well data. Figure 3 shows the NQDS plot highlighting, in green, the matched models.

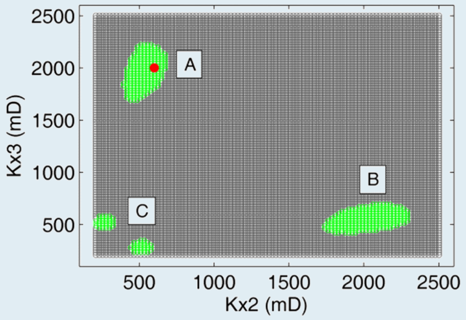

Figure 2: *Cross plot of Kx2 and Kx3 resulting from the exhaustive sampling (the red point represents the reference model).*

Clearly, we can see 4 disconnected group of matched models. The explanation for this result can be carried out with the aid of Figure 4, which shows the water saturation for different combinations of permeability values of Layers 2 and 3 after 480 days (first breakthrough time) of production. The combinations shown in Figure 4 are the central point of the groups of models shown in Figure 2.

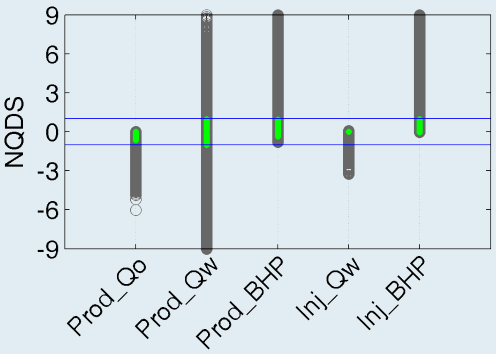

Figure 3: *NQDS plot.*

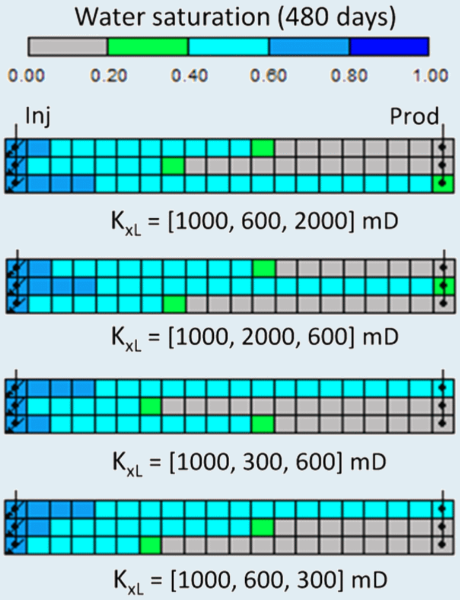

Figure 4: *Water saturation for different combinations of permeability values of Layers 2 and 3 after 480 days of production.*

According to the figure, one can see that for the combination KxL = [1000, 600, 2000] mD (Group A), the water arrives in the producer well through the Layer 3. For the combination KxL = [1000, 2000, 600] mD (Group B), the water arrives through the Layer 2. For the combinations KxL = [1000, 300, 600] mD and KxL = [1000, 600, 300] mD (the two separated Groups named C), the water arrives through the Layer 1. This occurs because the apportionment of the injected water (constant rate) is proportionally distributed based on the contrast of the permeability values. Therefore, the amount of water that arrives in the producer, independently of the layer, is nearly the same for the four combinations.

Forecast analysis

The matched models were extrapolated until 2700 days. A new producer well was included after the end of the history period in the middle (cell 11) of the reservoir, operating at QLmax of 80 m^3/d and minimum BHP of 15000 kPa. To maintain the pressure equilibrium, Qw_inj was increased to 160 m^3/d.
Figure 5 shows cumulative water production forecast for the 3 groups of models. We can note that Group A encompasses the reference solution (black points). However, although the well data is also matched for Group B and C (they have the same quality match of Group A), Group B is considerably different and Group C is completely different from the true case in the prediction period.

> *"Finding the best matched models may not be enough for reliable forecasts."*

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> *"The present analysis reinforces the necessity of performing robust uncertainty assessment processes."*

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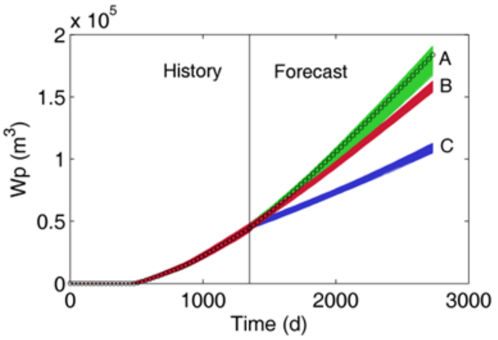

Figure 5: *Cumulative water production forecast for the 3 groups of models.*

Saturation map

Figure 6 shows similar plot as Figure 2. However, green points represent the models filtered taking into account, besides NQDS for well data, the NQDS for the water saturation (Sw). In this case, only the models in the region of the true case were selected. This happens because, although the wells are matched for the models of Groups B and C, the saturation map is matched only for the models of Group A. The combinations in the regions containing the pairs [2000, 600] mD (Group B), [300, 600] mD and [600, 300] mD (Group C) generate saturation maps very different from the true model, as shown in Figure 4.

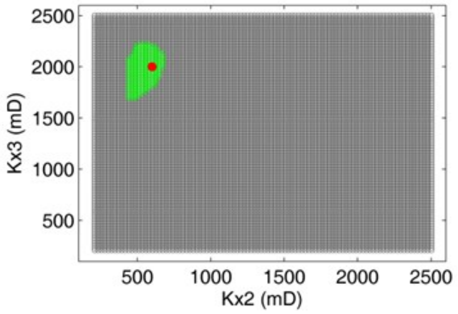

Figure 6: *Same as Figure 2 including NQDS of Sw.*

Discussion

There are three fundamental aspects that may contribute to the problem treated in this text: 1) amount of data available for the process, 2) the method (or methods) used in the history matching and (3) parameterization.

1) Amount of data: the amount (and quality) of dynamic data determines the degree of freedom of the HM problem. For example, production data from a few wells are not enough to mitigate uncertainties of a huge reservoir. Spatial dynamic data (derived from 4D seismic) may contribute to improve the history matching process.
2) Optimization and sampling methods: history matching is typically a high-dimensional and highly nonlinear problem. Thus, efficient exploration of the search space in order to find the best models is a big challenge for any optimization or sampling method. Optimization strategies that combine diversification and exploration of the search space and efficient sampling techniques can minimize the possibility of assessing only one local minimum.
3) Parameterization: this is the crucial aspect of the process. No methods find correct solutions if they are not into the search space. For example, in the model presented here, if the ranges of Kx2 and Kx3 were, for some reason, limited between 50 and 1500 mD, no method would be able to find the correct solutions (Group A). The only possible solutions would be those belonging to Group C. As describe previously, these models have a good well match, however, they generate wrong predictions.

Morosov and Schiozer (2016) carried out uncertainty quantification in production forecast in a realist reservoir model (UNISIM-I-D). They described a field development process and pointed out some intrinsic pitfalls in reservoir modeling that affect production forecast and claimed a reflection on the way reservoir uncertainty assessment is performed. The reading of their work is highly recommended.

Final remarks

1) The theoretical model used in the analysis presented in this text was useful to show, in a didactic manner, the multiplicity of solution of the history matching problem and the risk of assessing only local minimum, which can leads to unrealistic predictions.
2) This analysis reinforces the necessity of performing robust uncertainty assessment processes and the necessity of developing robust and efficient methods to deal with complex cases.
3) The benchmarks created by the UNISIM Group (UNISIM-I-D, for example) allow more realistic analyses, such as those carried out by Morosov and Schiozer (2016). The methodology used to construct the models permits to imitate the difficulties of a real case, allowing validation of new methodologies and providing insights to deal with real reservoirs.
4) As pointed out by Morosov and Schiozer, this kind of analysis is important to encourage the discussions about certain paradigms and possible pitfalls in reservoir modeling workflows towards new solutions to increase the reliability of production forecasts.

References

Morosov, A. L; Schiozer, D. J. "Field Development Process Revealing Uncertainty Assessment Pitfalls", SPE EUROPEC, Vienna, Austria, 2016.

Maschio, C.; Schiozer, D. J. "Probabilistic history matching using discrete Latin Hypercube sampling and nonparametric density estimation", Journal of Petroleum Science and Engineering, v. 147, pp. 98-115, 2016.

About the author

Célio Maschio is graduated in Mechanical Engineering from UNESP, obtained a MSc and a DSc degree in Mechanical Engineering from UNICAMP and is a researcher at UNISIM/CEPETRO/UNICAMP.

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