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Big Loop History Matching Using Virtual Wells

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Introduction

Numerical simulation is a powerful tool for the reservoir engineer for field development and management. Model calibration with history data is important to obtain reliable production forecast.

Integration with reservoir characterization is very important to the success of history matching and production forecasting, being essential to improve geological and numerical modeling (Gosselin *et al.*, 2003; Mezghani *et al.*, 2004) and build reservoir models consistent with multiple data types for the calibration and prediction period.

The main goal of this work is to illustrate the use of virtual wells in a big loop history matching. The general idea is to integrate history matching and reservoir characterization using virtual wells application based on pilot points (Floris, 1996).

In this work, we also apply a simultaneous calibration of different objective function (OF) in a history matching procedure, keeping the geological consistency.

Methodology

The methodology integrates reservoir characterization under uncertainties, the numerical simulation and history matching process (Figure 1).

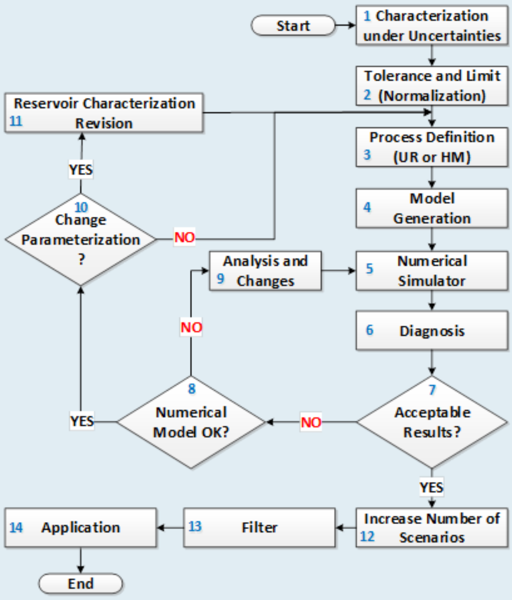

Figure 1: *Flowchart of the history matching, reservoir characterization and reservoir simulation integrated methodology (modified from Avansi* et al. *2016).*

The methodology follows fourteen steps as seen in Figure 1 and is described below:

1. Characterization under Uncertainties. The uncertain attributes present in the reservoir are surveyed. The range of uncertainties, the discretization levels, and the probability distribution are generated for each attribute.

2. Tolerance and Limit (Normalization). definition of the tolerance and limit for each objective function (OF) to calculate the normalized quadratic deviation with signal – NQDS (Avansi *et al.*, 2016).

3. Process definition (Uncertainty Reduction, UR or History Matching, HM). It is necessary to define between UR and HM. Besides both are being correlated, UR is the recharacterization process of the attributes based on the observed (historical) data and HM, an inverse problem, in its essence is the selection of reservoir models which best match the reservoir data (static and dynamic).

4. Model Generation. The characterized uncertain attributes are sampled based on Steps 1 and 3, combining discretized Latin hypercube (DLH) or DLH with geostatistical realizations (DLHG) to simulate the composition of the models (Schiozer *et al.*, 2016).

5. Numerical Simulator. Next, the generated models are run through a reservoir flow simulator.

6. Diagnostic. Well performance indicators, NQDS (Avansi *et al.*, 2016), are then used to diagnose the misfit between the models and the production history data, mainly in probabilistic approaches with a huge amount of information that should be analyzed concurrently. Using the NQDS indicator, we identify whether the results are acceptable for the proposed OF. The scenarios with normalized values from +1 to -1 (acceptance range) indicate good models.

7. Analysis of the Acceptable Results. Using a diagnostic plot, we identify whether or not the results are acceptable for the proposed OF.

8. Consistency of the Numerical Model. The consistency check of the numerical model is important to reproduce a physical condition of the reference (real) reservoir from production history data.

9. Analysis and Changes. If changes in the numerical model are necessary, a numerical and physical analysis is done to modify the numerical model.

10. Parameterization. A parameterization check is run if the numerical model is physical coherent. To assist this step, we analyze the NQDS for each OF.

11. Reservoir Characterization Revision. Uncertainty Reduction is reached when the scenarios are approximately grouped around the acceptance region. Parameterization of the reservoir model by adding a new attribute, new geostatistical image or changing the uncertainty range follows changing the limit of the uncertainty ranges of attributes adding new attributes or new geostatistical images. Before moving to the following step, we need to centralize the NQDS of all OF in the acceptance range in order to get better results.

12. Increase the Number of Scenarios. At the end, it is recommended to increase the number of filtered models by increasing the number of scenarios.

13. Model Selection (Filter). At this stage, we must filter all data sets simultaneously within the defined acceptance limits (Step 2).

14. Application. After selecting models that meet the UR or HM criteria, the application step closes the big loop workflow.

The focus of this work is Step 11, including a new geostatistical image in a process integrated with geostatistics to create virtual wells from synthetic profiles (geological model scale) with petrophysical properties (porosity and permeability), net-to-gross ratio, and facies, in which the permeability, facies and net-to-gross ratio are functions of the porosity.

We include virtual wells, based on the pilot point technique, in the geological model to promote controlled perturbations that are geologically consistent in reservoir regions that have not undergone control of matching procedure (Avansi *et al.*, 2016).

The virtual well approach provides a virtual log for wells controlling aspects of fluid flow in porous media, including porosity and facies. This method consists of:

1) allocating points in space from the location and the trajectory of a virtual well. Each virtual well assumes one node point for each geo-cellular grid from the top to the bottom of the reservoir. They are vertically perforated in the geological grid as a pseudo-log for the wells and the influenced region follows an ellipse based on the variogram model of porosity (Avansi and Schiozer, 2015);

> *"This work highlights a solution to the history matching problem integrated with reservoir characterization and numerical reservoir simulation, keeping the geological and numerical consistency of the generated models in a big loop history matching"*

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2) generating a porosity distribution along the well trajectory that correlates with the characteristics of the perturbation;
3) creating facies from the porosity pseudo-log to obtain the distribution of reservoir properties at the geo-cellular grid taken from the original and virtual wells, including only the real well data in the geostatistical analysis;
4) generating permeability and NTG distributions from porosity and facies respectively as described by Avansi and Schiozer (2015).

Virtual wells are manually added to specific regions of the reservoir based on the analysis of the water saturation map and the NQDS indicator.

Results

The results presented in the following topics are for the UNISIM-I-H model (Avansi *et al.*, 2016), focusing on step 10 – parameterization with new geostatistical images. We show one iteration which the objective was to improve PROD009 performance.

Figure 2 shows the NQDS results for all simulated models before (ST2H4g) and after (ST2H5) the parameterization procedure using virtual wells (each point represent one model). For practical purposes, only the NQDS for oil rate is delineated. Read Avansi *et al.* (2016) for more details.

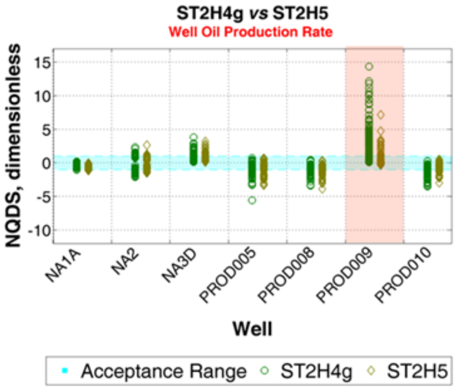

Figure 2: *NQDS of sub-cycle ST2H4g and cycle ST2H5 for oil rate for some producers, focusing on the PROD009. Colored circle and diamond markers represent the scenarios of sub-cycle ST2H4g and cycle ST2H5 respectively, light blue region (within -1 and +1), the acceptance range of all wells.*

Figure 2 presents a significant improvement in PROD009, centralizing the models in the defined acceptance range using the proposed virtual well technique integrated application.

The geological consistency is maintained, as shown in the histograms for permeability before and after the perturbation procedure of the geological model using virtual wells as in Figure 3.

Figure 3 shows that the distribution pattern of permeability remained the same after geomodel perturbation with the virtual well technique. Thus, the integrated process is as much as useful for the assisted history matching step, maintaining the consistency of the generated geological models in the proposed close big loop workflow.

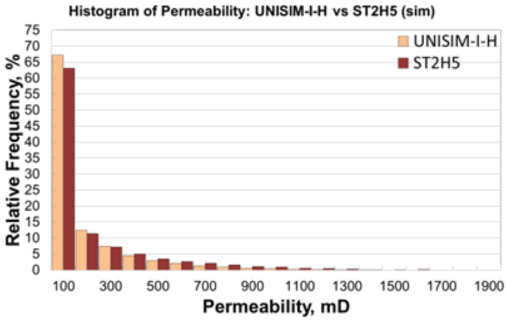

Figure 3: *Histogram of UNISIM-I-H model compared to one model of the ST2H5 cycle at simulation scale for permeability distribution. Light orange bars represent the histogram in the initial state of these properties, and dark red bars, the histogram after perturbation procedure using virtual well.*

Conclusions

A methodology for reservoir characterization using virtual wells is undertaken for the parameterization of the integrated process to geostatistics (geological realizations) and attributes, ensuring realistic geological models without creating geological discontinuities. The perturbation made in big loop history matching shows that it should not be an independent overprint on the static reservoir model. In addition, being the history matching an inverse problem, it should not be treated as optimization problem but as data integration which is consistent with static and dynamic data, mainly in probabilistic approaches.

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