Year 12, Number 4
112th edition
April, 2017

UNISIM ON-LINE

UNICAMP

Pilot wells as an auxiliary tool for history matching: Application to the Norne Field

Gil Fernando Gomes Correia

"This text describes the pilot wells methodology, based on the pilot point concept. The pilot wells are used to restrain and modify the geological model in order to find the geological configuration that best matches the reservoir flow behavior."

Introduction

History matching is an inverse process with many possible answers. This non-uniqueness requires further data sources such as seismic data and geological interpretations. Due to the many variables in a simulation model, it is often advantageous to parameterize the problem to reduce the dimensional space of the models' variables. Thus, various geostatistical-based parameterization techniques have been developed to integrate the production data with geological continuity information. The flexibility and consistency with the geostatistical assumptions make the pilot point method one of the most effective techniques to adjust regions with large misfit towards the observed data. However, the challenge is to find the optimum pilot point configuration (location and number of pilot points) for each case.

This text describes a pilot wells methodology, based on the pilot point concept, representing an extension of the virtual wells technique proposed by Avansi *et al.* (2016). The pilot wells are used to condition and modify the geological model to find the geological configuration that best matches the reservoir flow behavior. The methodology is applied to a real dataset: the Norne Field Benchmark case. The electrofacies database and the high-resolution datasets described by Correia and Schiozer (2016) form the working basis of the probabilistic and multi-objective history matching guided by pilot wells.

Methods

This work proposes the generation of new geostatistical models guided by pilot wells in an integration process between a geological modeling workflow and a wider history matching workflow (Correia, 2017). Similarly to the pilot points, the pilot wells are fictitious data used to affect realistic modifications in the reservoir regions surrounding the pilot wells. On the other hand, each pilot well can cross the entire reservoir, being also conditioned by the estimated variogram, similarly to the measured wells. Thus, the present approach uses far fewer pilot wells when compared with the traditional pilot point method. The values in the pilot wells are the parameters to be adjusted to modify the geological heterogeneity while minimizing the objective function. At other locations, the values are found through the geostatistical modeling techniques. The pilot wells methodology is chosen over other geostatistical parameterization techniques mainly due to the high flexibility in local adjustments.

In this study the pilot wells are synthetic wells with a vertical profile and a set of synthetic well logs. The facies profile is the main parameter to be manually or semi-automatically adjusted during the multiple workflow iterations, at each pilot well location. In the first case, each pilot well facies profile is entirely and manually modified (see G-segment case). In the second case, specific locations (i.e. specific horizons, interfaces, as shown in the dark boxes - Figure 1) are manually modified (see C-segment). The remaining pilot well profile is updated with the facies (at each pilot well location), from the models showing the lowest deviations during the diagnosis stages of the history matching process (outside dark boxes - Figure 1). The synthetic petrophysical properties are directly associated to the facies through an uncertainty range and, in this way, automatically modified within the same workflow iteration and/or between iterations. The uncertainty ranges correspond to different distributions (e.g. normal, log-normal) with upper and lower bounds determined during the data analysis process. This procedure avoids the generation of unrealistic property values and overcomes potential instability issues that frequently affect inverse problems.

Each geological modeling workflow run generates a set of multiple 3D facies and petrophysical models. For each set of models, the facies profiles are fixed at each pilot well location, similarly to the other measured wells. On the other hand, the petrophysical logs at each pilot well location are modified before running the scale up well logs process. In this way, each model is a modified version of the input synthetic well log (curve a). The new log (curve b) is modified using the standard deviation curve method according to the formula:

where *rand* refers to the random distribution (normal truncated) defined according to the objectives of each parameterization run and that modifies the petrophysi-

$$Curve(b) = Mean_{Curve(a)} + rand * StDev_{Curve(a)}$$

cal logs at the pilot wells locations. The *mean* and the upper and lower bounds of the random distribution are also defined by taking into account the objectives of each parameterization run, which means, after the diagnosis step in the history matching workflow. The facies log is used as a control property (Figure 1). The effect of the pilot wells in the reservoir properties redistribution is conditioned by the pilot wells configuration. Additionally, the geostatistical method, the variogram and the vertical and/or horizontal trends between properties also influence the efficiency of the pilot wells. The zone of influence of the pilot well can also be adjusted during the geostatistical modeling process by modifying the number of neighbors that are used for the Kriging.

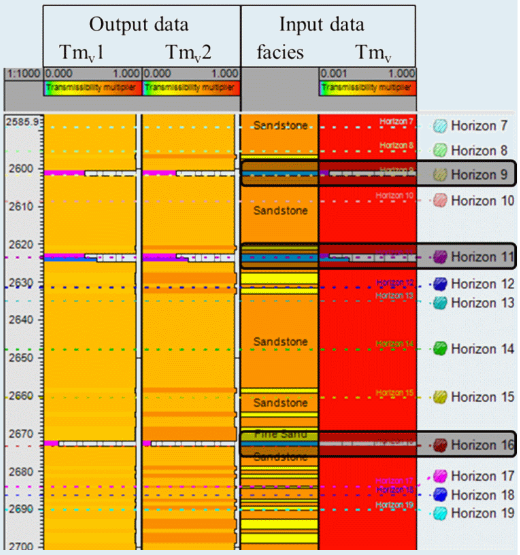

***Figure 1:** Input and output synthetic data on a pilot well. The interfaces highlighted with the dark boxes, coincident with the main position of the calcareous stringers (facies), are updated between iterations. Regarding the petrophysical properties, each output log realization (Tm_v1 and Tm_v2) is a modified version of the input synthetic log (Tm_v).*

The total number of pilot wells and their location is one of the key issues of the method, highly dependent on the reservoir characteristics (geological scenario and reservoir flow behavior). In this study, the configuration takes into account: (1) Geological framework: sedimentary features with a significant impact in the reservoir flow behavior (e.g. channels, stratigraphic barriers); (2) other datasets: 3D and/or 4D seismic data (depositional/stratigraphic features); (3) Streamline simulations: used to define zones-of-influence of producers and, between injectors and producers, allowing the jointly history match of multiple wells using the pilot wells method. The main streamlines paths are settled as the preferred locations to manually spread the pilot wells; (4) Production data: the outcome analysis of the NQDS values and production curves during the diagnosis step of the history matching process.

Specials interests:

- UNISIM
- UNISIM Publications
- Reservoir Simulation and Management Portal
- Previous Issues

Links:

- UNICAMP
- Cepetro
- Petroleum Engineering Division
- School of Mechanical Engineering
- Petroleum Sciences and Engineering

Graduate:

Petroleum Sciences and Engineering: interested in Masters and PhD in the Simulation and Oil Reservoir Management area click here.

"The flexibility of the pilot wells, adapting to different geological contexts and to different data sources, turns this method an adequate tool to characterize highly heterogeneous reservoirs and understand their production behavior."

UNISIM opportunities:

If you are interested in working or developing research in the UNISIM Group, please contact us.
Immediate interest in:

- Researcher in the simulation area, management and reservoir characterization.

For further information, click here.

Application

The methods are applied to a real dataset, the Norne field benchmark case, a siliciclastic reservoir, located between the Vøring and Møre basins in the Norwegian Sea.
The simulation model available in the Norne field benchmark database is built in the Eclipse 100 simulation software, later converted to the CMG-IMEX simulation software, resulting in a few modifications to adequate the procedures to the tools developed by the UNISIM research group, while ensuring the physical and numerical consistency of the reservoir models.

Results

Two case studies are chosen to show different pilot well approaches applied to different segments of the Norne field reservoir: the G-segment and the C-segment.
Regarding the G-segment and following the indicators from the diagnosis stage, the main goal is to model a channel using a pilot wells grid. As a general guideline for selecting the number of pilot wells, the distance among them must be smaller than the structure to be represented, for instance, smaller than the channel width. All pilot wells are located between the pair injector/producer, a region without wells, thus with higher geological uncertainty. The Figure 2 shows the configuration that best preserves the channel configuration in all models, maintaining at the same time some uncertainty regarding the channel petrophysical properties and dimensions. In this case study, the facies are manually placed according to the stacking pattern of a sedimentary channel (shale content increasing towards the channel flanks) and of the Garn Formation (coarsening upwards trend). The petrophysical properties are defined according to the same uncertainty ranges determined during the data analysis stage.

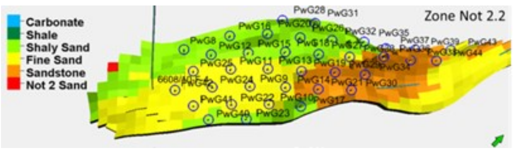

***Figure 2:** Channel configuration in the Not 2.2 zone of the G-segment.*

The differences in the geological background of the C-segment when compared with the G-segment, led to the generation of another geological scenario and to differences in the pilot wells configuration. The main challenge is to map properly the calcareous stringers that may act as stratigraphic barriers to the vertical fluid flow.
In opposition to the G-segment, an irregular pilot wells grid is chosen, with the pilot locations following the main water flow paths between different injectors/producers pairs obtained from the streamline analysis.
The pilot wells are grouped according to the different injectors/producers pairs (Figure 3). Thus, each pilot well group has a major influence in a specific producer and a lower influence over the facies and petrophysical properties. The aim is to cause a gradual perturbation in the reservoir. After obtaining a good match for a specific well, the properties of that pilot wells group are fixed, continuing to disturb the properties of the other groups.
The modifications in the geological model introduced by the pilot wells are very helpful to find the geological configuration that best matches the reservoir flow behavior (Figure 4).

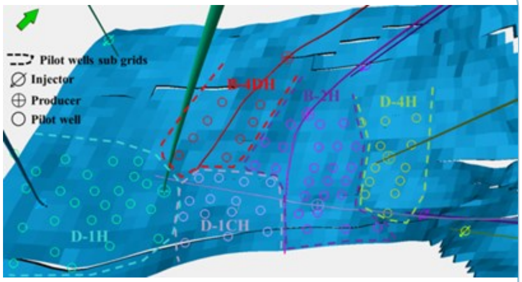

***Figure 3:** Pilot wells configuration at the end of the iteration 3B. There are 5 pilot wells groups, each one with a major effect on the producer that names each pilot well group.*

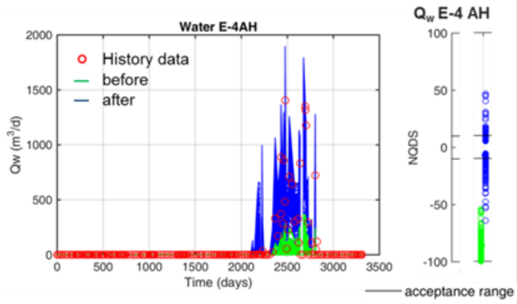

***Figure 4:** Water rates and NQDS results of all models (200) before and after the implementation of the pilot wells grid in the G-segment (well E-4AH). Lower NQDS values indicate better matching quality.*

Conclusions

Taking into account both case studies and the integration with the geological and reservoir simulation stages, the pilot wells method proved to be advantageous, namely in local adjustments, due to the following aspects: (1) high flexibility, adapting to different geological contexts and to different data sources; (2) honors the variograms; (3) the petrophysical properties were changed according to the modifications in the facies distribution. The facies were guided by the pilot wells and by geostatistical modeling methods, honoring the properties ranges estimated during the data analysis, and leading to 3D models geologically more consistent; (4) the integration with history matching stages was essential to measure the effects of each modification, giving at the same time the necessary clues to change the pilot wells configuration between each iteration.

References

Avansi, G.D., Maschio, C. and Schiozer, D.J. 2016. Simultaneous history-matching approach by use of reservoir-characterization and reservoir-simulation studies. SPE Reservoir Evaluation & Engineering, v.19, pp.694-712.

Correia, G.G. 2017. Integration of reservoir characterization with history matching guided by pilot wells: application to the Norne field. PhD Thesis, UNICAMP, Campinas, Brazil.

Correia, G.G., and Schiozer, D.J. 2016. Reservoir characterization using electrofacies analysis in the sandstone reservoir of the Norne Field (offshore Norway). Petroleum Geoscience, V.22, pp.165-176

About author:

Gil Correia holds a degree in Geology and a MSc in Petroleum Geology, from the University of Coimbra, obtained a PhD in Petroleum Science and Engineering from UNICAMP. Since 2012, he is a researcher at UNISIM/CEPETRO/UNICAMP.

For further information, please visit
http://www.unisim.cepetro.unicamp.br

Research in Reservoir Simulation and Management Group

Petroleum Engineering Division - Energy Department
School Of Mechanical Engineering
Center for Petroleum Studies
University of Campinas
Campinas - SP

Phone: 55-19-3521-1220
Fax: 55-19-3289-4916

unisim@cepetro.unicamp.br