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A Visual Steering Software for Geological Well Testing

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SUMMARY

Conventional well test interpretation is based on employing simplified analytical models for parameter estimation. However, an enhanced use of the well test data for the reservoir characterization is only attained using geological well testing. Geological well testing is used to validate the dynamic response of the model using available pressure transient tests. This paper presents a novel visual steering framework for dynamic validation of the reservoir models using the well test data. The software has the ability of correlating the 3D models with the well test diagnostic curves for detecting the influence of the reservoir and fluid heterogeneities on the transient behavior of the model. The engineer is able to update the geological model using various facilities embedded in the software using manual and/or assisted history matching approaches. We show a challenging well test response in a faulted channelized environment in a gas condensate reservoir and present a sensitivity study to understand and interpret such a complicated well test response using our developed framework. This work is aimed at designing a multi-source, multi-domain framework for efficient data integration within an engineering workflow.

Introduction

Transient well test data are amongst the earliest dynamic data that are acquired from the reservoir in the exploration phase, which have a key impact on the reservoir development and decision-making. Well test pressure transients reflect important information about the reservoir heterogeneities, which is fundamental to the reservoir description. Analytical well test interpretations that are based on simplified mathematical models can provide some important information on the average reservoir properties and structures. However, full integration of well tests with the static data is only possible through the so-called geological well testing (Hamdi, 2012; Hamdi, 2014; Hamdi et al., 2014b). Geological well testing is a geo-engineering workflow (Corbett, 2009) assisting in the dynamic illumination of geological and fluid heterogeneities (Hamdi et al., 2013). This is a forward/inverse modeling approach to analyze the independent or combined effect of reservoir and fluid properties and/or validate the static model based on the well test data in a manual (Hamdi et al., 2014b) or an assisted history matching approach (Hamdi et al., 2014a; Hamdi et al., 2015). The outcrop data, experimental laboratory fluid data, seismic, core and log data along with considerable uncertainties are integrated into a geological model to build a spatial static model. The geological well testing is used to close the loop of reservoir description/validation by conditioning the static reservoir model using dynamic well test data, particularly in the early stages of reservoir exploration.

Geological well testing requires a unique framework with direct access to geological and simulation models to correlate the well test data events with the 3D reservoir models. In this sense, the reservoir engineer will be able to directly access different sources of data and to focus on defining meaningful workflows rather than spending the time on data transformation between different platforms (e.g. well test, numerical simulation and visualization packages) for a better interpretation. This process requires the ranking and updating the heterogeneities based on their ability to revamp the output of a geological model. A visual steering for geological well testing provides a tool to visualize reservoir model and simulation data, and to visually update models. Therefore, a unified platform is developed to analyze the dynamic responses of the models and reduce the uncertainty associated with the reservoir static models for better decision-making and prediction of the reservoir performance.

Our framework's input is a reservoir simulation grid, tested and refined through geological well testing. The fundamental framework includes the integration of well test specialized plots (log-log, Cartesian and semi-log plots with some analytics) and 3D visualization and analytics of reservoir and well data. This process is also enriched by adding some assisted history matching techniques for automatic matching of the well test data, in addition to the already available manual matching techniques. This takes advantage of interactivity with informative visualization and analytics i.e, the reservoir engineer shall control all steps of the prototyping process, being able to automatically fine-tune the reservoir properties with all available actual data towards the precision desired.

Software development and capabilities

The software is implemented in C++/Qt, which makes it readily available for all major platforms (Microsoft Windows, Apple OS X and Linux) without sacrificing the software performance. The internal mesh structure and geometric primitives are provided by an in-house developed library iRES, which was tailored for the efficient handling of big data sets visualization. The final rendering of the 3D models is done through OpenGL's vertex shaders (to handle geometric data) and fragment shaders (to handle the rendering in the pixel's level).

In summary, the current version of the developed software has the ability of

1. Fast co-visualizing multi-rate well test diagnostic plots and the geological/simulation 3D models
2. Basic well test straight line analysis for determination of flow regime and quick parameter estimation

3. Basic statistics including but not limited to the histograms, power averaging and Lorenz coefficient (Lc) for relating the reservoir cell heterogeneities to the parameters from the analytical well test
4. Visually modifying the filtered cell and the numerical simulation parameters for running multiple numerical well test simulations in a manual history matching routine. The software is currently compatible with CMG IMEX and GEM simulators.
5. Plugging-in an assisted history matching technique (i.e. differential evolution)

Using the proposed prototype, the user is able to navigate through the model with flexibility of interaction between well test and 3D plots for better understanding of the effect of heterogeneities on the well test response. Using this software, the requirement of using a multiple number of software for data extraction and display is removed. The engineer can define any workflow as the one documented by Hamdi et al. (2014b) for display and mixing various facies realizations where a match to the real data is required by some model hybridization. The Lorenz plot and other basic statistics can help relate the simple quantitative heterogeneities such as Lc and power average permeabilities from the core and filtered spatial simulation data to the one obtained from the well test data. In a more detailed study, the dynamic impact of geostatistical parameters such as variogram type, correlation length or nugget effect can be easily investigated by plugging a geostatistical package such as GSLIB (Deutsch and Journel, 1992). An example of such workflows has been documented by Hamdi (2014).

Example

Figure 1. shows a snapshot of the software environment visualizing the 3D facies model and the well test diagnostic plots (with corresponding straight lines) of a complex faulted gas condensate reservoir. The model has been constructed using a 3D training image through multi-point facies statistics and has 217×226×42 cells in x-, y- and z- directions respectively. Each cells measures an average volume of 18×18×4 m^3 of the reservoir volume. Sequential Gaussian Simulation (Deutsch, 2002) has been used to populate the porosity data, and some porosity and permeability cross-plots were implemented to estimate the lateral permeability values. The reservoir model represents a typical channelized environment where the high permeable sand bodies (Figure 1: red color with a typical average permeability of 75 md) are effectively isolated within the pervading very low-permeability reservoir facies (Figure 1: light and dark blue color with a typical k~0.001 md). The cocooning effect of the low perm facies with a reduced vertical communication between the permeable layers forms an effective commingled system.

A black oil reservoir simulator with a local grid refinement and logarithmic timesteps has been used to simulate the well test response of this model. The well has sparsely perforated through some layers of the reservoir which complicate finding a reliable analytical model. A sensitivity study has been performed to probe the impact of skin, fault transmissibility and the condensate dropout on the well test response using our software for a unique interaction with the 3D model.

The well test signature of such a model is a ramp effect response (Hamdi, 2014; Hamdi et al., 2014b) with a steady increase of the well test derivative curve over a few log cycles. An apparent radial flow regime indicated with zero slope line (corresponds to an effective gas permeability of about 5 md), a steep rise in the pseudo-pressure derivative curve (> one-half slope) and a late time flattening of the derivative curve (that crosses the pseudo-pressure drop curve) further complicate the analytical interpretation. A consistent interpretation is not attained without careful navigation through the 3D model to understand the investigation of diffusion front within the facies transitions and the areas with condensated fluid. We aim to highlight the effect of fluid, structural and facies heterogeneities on the well test response.

Our software helped investigate this typical problem by comparing the well test diagnostic plots (with its straight-line features) along with the readily available 3D visualizations of the filtered cells and their statistics. Figure 2 shows the filtered cell of the first layer at the shut-in time using the spatial pressure difference of the reservoir cells (P_i-$P_{shut\text{-}in}$). All cells having the values less than a threshold (say 1% of the maximum pressure drop) are filtered while the oil saturation changes (Figure 2.A) and the facies (Figure 2.B) are mapped on top of the current cells. A detailed study revealed that the late time crossing is related to superposition and the cocooning effect of the low quality facies where the lateral permeability reduces to very low values but not zero. This is the same as the real case study by Hamdi et al (2014). The late time flattening of the derivative curve is related to an increased fault transmissibility from zero to unity (see the log-log well test plot in lower left panel of the software in Figure 1). The 3D filtering of the pressure drop (not shown here) indicated that only the lower layers of the model that are abundant with the high permeable facies passes over the fault at the very late times.

In the other sensitivity case and for the sake of illustration, the impact of the skin value on the pressure history curves has been examined. The comparative linear well test plots for the cases with skins of zero and 5 are shown on top the software snapshot as depicted on Figure 1. The user can always perform basic analytical well test study within the software using the straight line analysis.

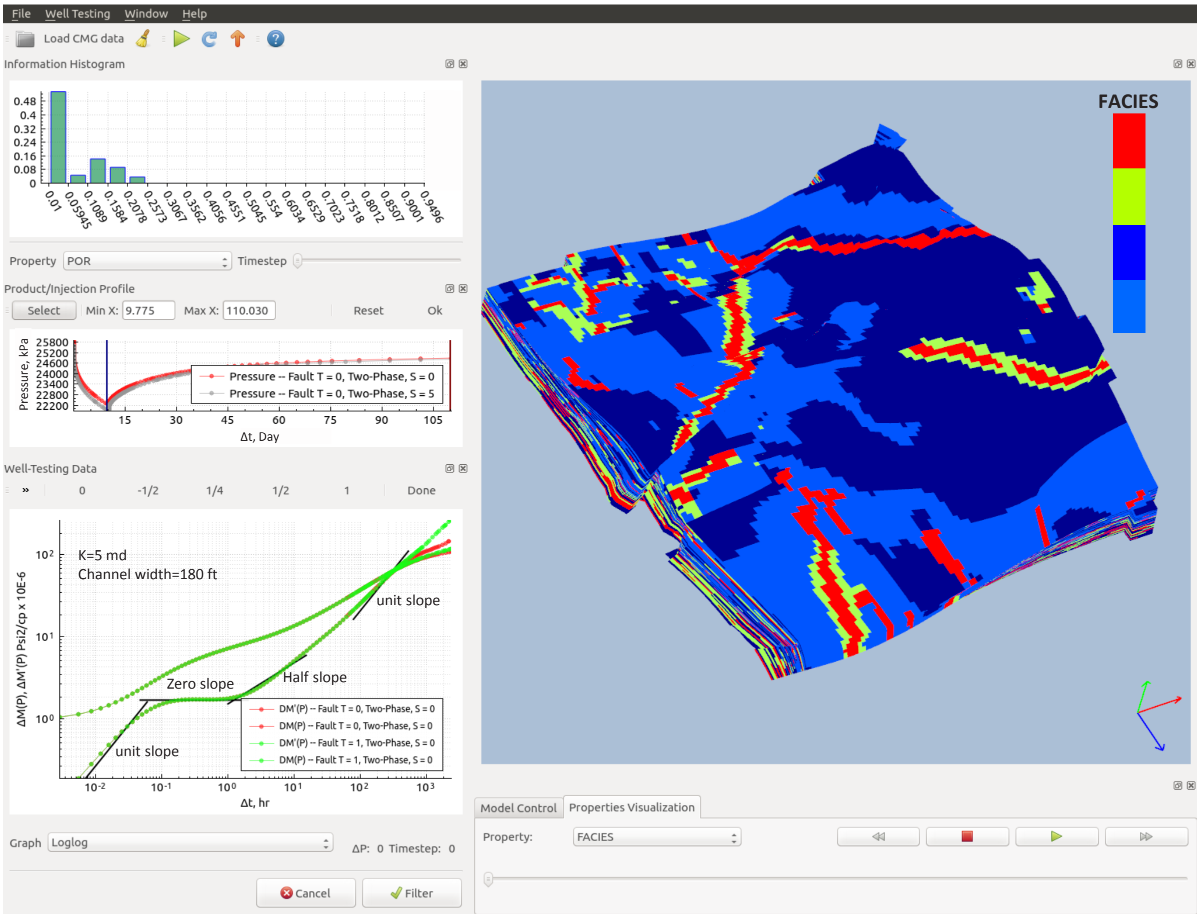

Figure 1. A snapshot of the software environment showing the 3D facies model and some simulated well test curves.

In the next development stage, this framework will also provide the ability for co-visualization and analytics of other data, including but not limited to the well-log, 3D and 4D seismic volume/maps to assist the specialists in updating, constrained interpretation, and the realistic parameter tuning in the well test domain. Hence, the final target we seek is to design a multi-source, multi-domain framework for efficient data integration within an engineering workflow.

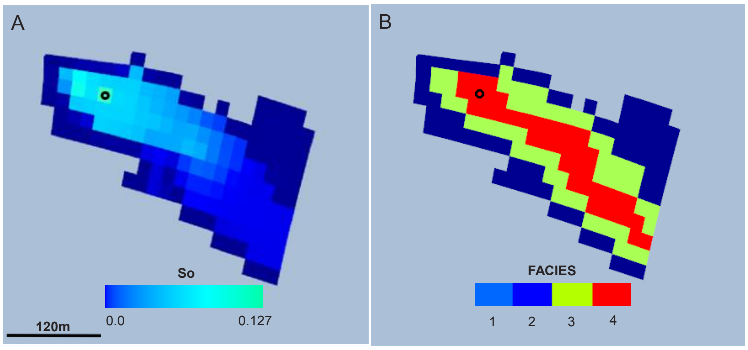

Figure 2. *Filtered cells at layer 1 of the model at the shut in time with mapping the oil saturation (A) and the facies transition (B).*

Conclusions

A unified framework has been developed for better use of well testing data into the reservoir characterization process. The software has the flexibility of fast visualization of the reservoir simulation and well test data for dynamic validation of the reservoir model using the manual and assisted history matching techniques. An illustrative example was shown to present a simple but systematic sensitivity study using our software to relate the effect of spatial fluid and rock heterogeneities on the well test response of a complex faulted channelized reservoir with a gas condensate fluid. The ramp effect well test response was diagnosed and was related to the cocooning effect of the low permeability facies.

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References

Corbett, P.W.M., 2009, *Petroleum Geoengineering: Integration of Static and Dynamic Models*, EAGE/SEG, 90 p.

Deutsch, C.V., 2002, *Geostatistical Reservoir Modelling*: USA, Oxford University Press, 384 p.

Deutsch, C.V., and Journel, A.G., 1992, *GSLIB: geostatistical software library and user's guide*, Oxford University Press, 340 p.

Hamdi, H., 2012, *Illumination of Channelised Fluvial Reservoirs Using Geological Well Testing and Seismic Modelling*: *PhD thesis*, Unpub. PhD Thesis, Heriot-Watt University, 247 p.

Hamdi, H., 2014, Well-test response in stochastic permeable media: Journal of Petroleum Science and Engineering, **119**(0), p. 169-184.

Hamdi, H., Hajizadeh, Y., Azimi, J., and Sousa, M.C., 2014a, Sequential Bayesian Optimization Coupled with Differential Evolution for Geological Well Testing, presented at the 76th EAGE Conference and Exhibition 2014 Amsterdam, the Netherlands.

Hamdi, H., Hajizadeh, Y., and Costa Sousa, M., 2015, Population Based Sampling Methods for Geological Well testing.: Under review with Oil & Gas Science and Technology.

Hamdi, H., Jamiolahmady, M., and Corbett, P.W.M., 2013, Modeling the Interfering Effects of Gas Condensate and Geological Heterogeneities on Transient Pressure Response: SPE Journal, paper SPE SPE-143613-PA, **18**(4), p. pp. 656-669.

Hamdi, H., Ruelland, P., Bergey, P., and Corbett, P.W.M., 2014b, Using geological well testing for improving the selection of appropriate reservoir models: Petroleum Geoscience.