

Convolution Explorer Application: What Is It?

Convolution Explorer is a software application for *Dynamic Reservoir Analysis* of well test and surveillance-type pressure and rate data. As an application, this software includes two modules:

1. ***Convolution Explorer module,***
2. ***Response Generator module.***

The application can be configured to include only Convolution Explorer module. In this configuration, the application is fully functional and provides all the functionality for *Dynamic Reservoir Analysis*. The application can also be configured to include two modules. *Response Generator* module provides additional simulation functionality that allows incorporate into analysis geo-seismic reservoir information reflected in a reservoir map. It allows to build reservoir models that reflect the reservoir geometry and architecture and verify/confirm that the analysis conclusions of the dynamic analysis of well pressure and rate data alone are consistent with the reservoir geometry and architecture. This adds to the confidence that the analysis conclusions are correct.

Convolution Explorer Module. Well test data are normally obtained in exploration and appraisal well tests performed during reservoir discovery and appraisal while surveillance data (pressure and rate history) are acquired during well production operations. Well test data are normally analyzed by Pressure Transient Analysis (PTA) techniques while surveillance pressure and rate data are usually analyzed by the methods of Production Data Analysis (PDA). *Convolution Explorer* offers an alternative approach for analysis of both types of data. It brings the two analysis approaches, PTA and PDA, to a common foundation, simplifies the analysis workflow, eliminates the need for different software tools, and elevates analysis of surveillance data to the same level of rigor as that of pressure transient analysis.

The main objective of Dynamic Reservoir Analysis is to obtain estimates of reservoir and well properties that are required for efficient reservoir development and exploitation. Such reservoir properties like formation permeability, large-scale heterogeneities, understanding of reservoir architecture and reservoir connectivity across large distances from the wells allow us to make realistic expectations of the well productivity achievable in the reservoir. An estimate of reservoir pore volume supported by dynamic data together with well productivity allow us to decide on the number of wells required for field development and on the individual well placement.

This type of dynamic reservoir analysis is possible because the well pressure and rate data acquired in exploration and appraisal well testing and during early reservoir production depend on the above reservoir properties and these properties are somehow encoded/reflected in the observed dynamic reservoir behavior. This fact is a necessary requirement for the success of dynamic data analysis i.e., extraction of important reservoir information from the data.

While this requirement is generally satisfied and the observed dynamic data do depend on reservoir properties, this alone is not sufficient for successful dynamic analysis. At the dawn of PTA development, it has been recognized that successful analysis is possible not for any type of dynamic data but for the data that are appropriately structured, when the well is produced in a

sequence of flow periods. During each such flow period the well is produced at a relatively stable and constant rate. The well rate may change from one period to the next. In this sequence of flow periods there should also be periods when the well is shut in and the well rate is zero. Fortunately, this is the type of production sequences used in routine reservoir production operations. By appropriately structuring the well production sequence we control encoding of the reservoir and well properties in the well dynamic data and thus assuring success of future analysis.

Analysis of appropriately structured data is relatively straightforward. However, a large number of methods, techniques, and software tools available in the analysis industry developed over the last several decades brings confusion and does not offer a fast and direct path way to the analysis results. Instead, an engineer gets sidetracked to building reservoir models and matching observed dynamic behavior with the help of these models. All this leads to a time consuming and expensive reservoir simulation exercise while a more straightforward and simple approach exists that allows one to reach the same or even more definitive conclusions and results and at the same time develop a deeper understanding of what the data tell us about the reservoir, its properties, connectivity, geometry of fluid flow in the reservoir. This is exactly the analysis approach offered by the *Convolution Explorer* application module. Convolution Explorer implements an analysis technique based on pressure-rate deconvolution that is applicable for both well test and surveillance-type data.

This approach does not rely on any automatic pressure-rate deconvolution algorithms which are often too restrictive and are not robust enough for surveillance type data acquired in the course of routine production operations. In this approach a characteristic constant-rate drawdown response function is reconstructed manually using specialized functionality implemented in this software tool. In the course of this reconstruction, the well response function is derived by matching observed well pressure data with the result of convolution of the well rate data and the reconstructed response function. The shape of the response function is adjusted manually until an acceptable match to the well pressure history is achieved.

In this reconstruction the drawdown response function is derived in the form of the Bourdet derivative plot with reservoir and well parameters (permeability, skin, fracture length, distance to a boundary, reservoir pore volume, and so on) estimated directly from that analysis plot using standard PTA methods. The derived drawdown response function, which is a reflection of observed well behavior, can then be used to forecast future well rate performance for different scenarios of pressure constraints imposed on the well.

Convolution Explorer module is not limited to single well analysis problems. It can be used with multi-well data. In multi-well reservoir situations, the bottomhole pressure observed in a well is affected by the well's own production and by production of other wells in the reservoir. In multi-well situations the dynamic analysis problem becomes significantly more complicated and requires reconstruction of not only drawdown self-responses but also of all interference responses between wells. Convolution Explorer provides all the necessary functionality required for response reconstruction in this case.

Convolution Explorer module is not limited to single-layer reservoirs either. It can also be used for multi-layer reservoir analysis where each layer represents a reservoir interval/sand separated

from other layers above and/or below by impermeable shales. Multi-layer reservoir systems are distinguished by specific pressure behavior associated with crossflow between layers that occurs through wellbore. In some situations, such crossflow may not be significant and could be ignored. In these situations, a multi-layer reservoir will behave like a single-layer reservoir system and analysis could be done using single-layer dynamic analysis approach. In other situations, crossflow between layers may be significant and analysis will require a multi-layer formulation. Layer crossflow depends on the contrast of layer properties. *Convolution Explorer* module includes a multi-layer analysis option that allows us to account for crossflow between layers when reconstructing drawdown layer responses. We should note, however, that dynamic reservoir analysis in these situations becomes even more difficult.

Convolution Explorer module can be configured to provide different combinations of these analysis options:

1. Single-well single-layer,
2. Multi-well single-layer,
3. Single-well multi-layer,
4. Multi-well multi-layer.

Response Generator Module. Response Generator is a boundary element-based single phase reservoir simulation software for accurate simulation of fluid flow in reservoirs. It can be used for simulation of fluid flow in oil as well as gas reservoirs with fairly complex reservoir architecture. The solution algorithm implemented in this simulator does not require and does not use areal gridding. The simulator produces very accurate transient quality solutions. The simulated well pressure can be directly compared with the pressure measured by downhole pressure gauges in the same wells. This allows the user to focus on accurate representation in a reservoir model of the reservoir physical features and properties that actually control fluid flow in the reservoir and not worry about gridding and its effects on solution accuracy. Response Generator provides reasonable assurance that simulated well pressure has sufficient accuracy for its direct comparison with the pressure measured in the same well.

Response Generator is an interactive software where the user has the ability to define a reservoir model interactively on a computer screen by defining elements of a reservoir model (reservoir geometry, reservoir regions, well locations, faults) according to a reservoir map. Response generator is limited to 2-D simulation problems. However, it allows one to build multi-layer models where wells may produce from several layers separated vertically by shales with possible cross-flow through the wellbore taking place between layers.

In addition to being interactive, the simulator is also very fast. It allows the user experiment with different reservoir model scenarios, generate solutions, see effects of model changes on simulated pressure behavior and immediately assess whether these model changes are supported by the pressures observed in the wells. Using this simulator together with the analysis

capabilities offered by the Convolution Explorer module allows one to bring into analysis along with the dynamic pressure and rate data the geologic reservoir description and spatial information reflected in the reservoir map. It allows to confirm that the conclusions derived from dynamic data are also consistent with geo-seismic information reflected in the reservoir map. This adds confidence in the conclusions of the dynamic reservoir analysis produced using Convolution Explorer analysis workflow.

In this implementation of boundary element-based simulator, it is used for computation of unit-rate drawdown response functions (both self-responses and interference responses) between wells. This is why this simulation module within the Convolution Explorer application is called Response Generator.

Simulated pressure responses produced by Response Generator simulation module can be compared with the responses reconstructed directly from dynamic data using Convolution Explorer analysis functionality. Simulated well pressures are computed by convolving simulated responses with well rates. We do this using the same convolution algorithm (single-well or multi-well) that is used in the Convolution Explorer module.

Response Generator is based on linear formulation of fluid flow in the reservoir. As a result, it can only be used for simulation of single-phase flow in reservoirs when the pressure in the reservoir remains above the bubble point or the dew point pressure of reservoir fluid. However, the fluid flow formulation in Response Generator is generalized through the use of special variable transforms that allow to account for the non-linear effects associated with pressure dependent fluid properties. This extends Response Generator application to gas reservoirs where pressure dependent gas properties have significant effects on gas flow in the reservoir.