Top-Down Modeling; Practical, Fast Track, Reservoir Simulation & Modeling for Shale Formations

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SUMMARY

This article reviews a new reservoir simulation and modeling technology called Top-Down, Intelligent Reservoir Modeling (Top-Down Modeling for short) for the shale formations with examples presented for New Albany, Lower Huron and Marcellus Shales. Top-Down Modeling technology integrates reservoir engineering with artificial intelligence and data mining. Advantages of this new modeling technology include its flexible data requirement, short development time and ease of analysis.

Traditional reservoir simulation and modeling is a bottom-up approach. It starts with building a geological model of the reservoir followed by adding engineering fluid flow principles to arrive at a dynamic reservoir model. The dynamic reservoir model is calibrated using the production history of multiple wells and the history matched model is used to strategize field development in order to improve recovery.

Top-Down Modeling approaches the reservoir simulation and modeling from an opposite angle by attempting to build a realization of the reservoir starting with well production behavior (history). The production history is augmented with core, log, well test and seismic data (upon availability of each) in order to increase the accuracy and fine tune the Top-Down model. The model is then calibrated (history matched) using the most recent wells as blind dataset. Although not intended as a substitute for the traditional reservoir simulation of large, complex fields, this novel approach can be used as an alternative (at a fraction of the cost and time) to traditional reservoir simulation in cases where performing traditional modeling is cost (and man-power) prohibitive, specifically for shale formations. In cases where a conventional model of a reservoir already exists, Top-Down Modeling should be considered a complement to, rather than a competition for the traditional technique. It provides an independent look at the data coming from the reservoir/wells for optimum development strategy and recovery enhancement.

Top-Down Modeling is an elegant integration of state-of-the-art in Artificial Intelligence & Data Mining (AI&DM) with solid reservoir engineering techniques and principles. It provides a unique perspective of the field and the reservoir using actual measurements. It provides qualitatively accurate reservoir characteristics maps that can play a key role in making important and strategic field development decisions.

TOP-DOWN INTELLIGENT RESERVOIR MODELING

Traditional reservoir simulation is the industry standard for reservoir management. It is used in all phases of field development in the oil and gas industry and is being used on some shale formations. The routine of simulation studies calls for integration of static and dynamic measurements into the reservoir model. It is a bottom-up approach that starts with building a geological (geo-cellular) model of the reservoir. Using modeling and geo-statistical manipulation of the data the geo-cellular model is populated with the best available petrophysical and geophysical information. Engineering fluid flow principles are added and solved numerically to arrive at a dynamic reservoir model. The dynamic reservoir model is calibrated using the production history of multiple wells in a process called history matching and the final history matched model is used to strategize the field development in order to improve recovery.

Characteristics of the traditional reservoir simulation and modeling include:

1. It takes a significant investment (time and money) to develop a geological (geo-cellular) model to serve as the foundation of the reservoir simulation model.
2. Development and history matching of a reservoir simulation model is not a trivial process and requires modelers and geoscientists with significant amount of experience.
3. It is an expensive and time consuming endeavor.
4. A prolific asset is required in order to justify a significant initial investment that is required for a reservoir simulation model.

Top-Down Intelligent Reservoir Modeling that can serve as an alternative or a complement to traditional reservoir simulation and modeling starts with well-known reservoir engineering techniques such as Decline Curve Analysis, Type Curve Matching, History Matching using single well numerical reservoir simulation, Volumetric Reserve Estimation and calculation of Recovery Factors for all the wells (individually) in the field.

Using statistical techniques multiple Production Indicators (3, 6, and 9 months cumulative production as well as 1, 3, 5, and 10 year cumulative gas production) are calculated. The reservoir engineering analyses mentioned above along with the statistical data that is generate form the basis for a comprehensive spatio-temporal database. This database represents an extensive set of snap shots of gas flow in the shale formation. This large volume of data is processed using the state-of-the-art in artificial intelligence and data mining (neural modeling, genetic optimization and fuzzy pattern recognition) in order to generate a complete and cohesive model of the entire reservoir. This is accomplished by using a set of discrete modeling techniques to generate production related predictive models of well behavior, followed by intelligent models that integrate the discrete models into a cohesive picture and model of the reservoir as a whole, using a continuous fuzzy pattern recognition algorithm.

The Top-Down Intelligent Reservoir Model is calibrated using the most recent set of wells that have been drilled in the field. The calibrated model is then used for field development strategies to improve and enhance hydrocarbon recovery.

Given the brief nature of this article, only short synopses of three Top-Down models that have been developed for New Albany, Lower Huron and Marcellus Shale plays are presented here. Readers are encouraged to refer to other publications by the authors for more in-depth coverage of how Top-Down models are developed and validated using synthetic as well as actual reservoirs.

APPLICATION OF TOP-DOWN MODELING TO NEW ALBANY SHALE

Detail of Top-Down modeling application to New Albany Shale can be found in a recently published SPE paper[1]. Figure 1 shows the location of the New Albany Shale and the portion of the formation that was used in the Top-Down modeling along with well locations, the Cartesian and the Voronoi grid that was used to identify the Estimated Ultimate Drainage Area (EUDA) for each well. This is an important first step in development process of Top-Down models. This figure also shows the permeability and the initial gas in place distribution determined using the type curve matching and volumetric calculations in the Top-Down modeling workflow.

[1] Top-Down Intelligent Reservoir Modeling of New Albany Shale. A. Kalantari & S. Mohagegh, SPE 125859, Proceedings, 2009 SPE Eastern Regional Conference & Exhibition. Charleston, West Virginia.

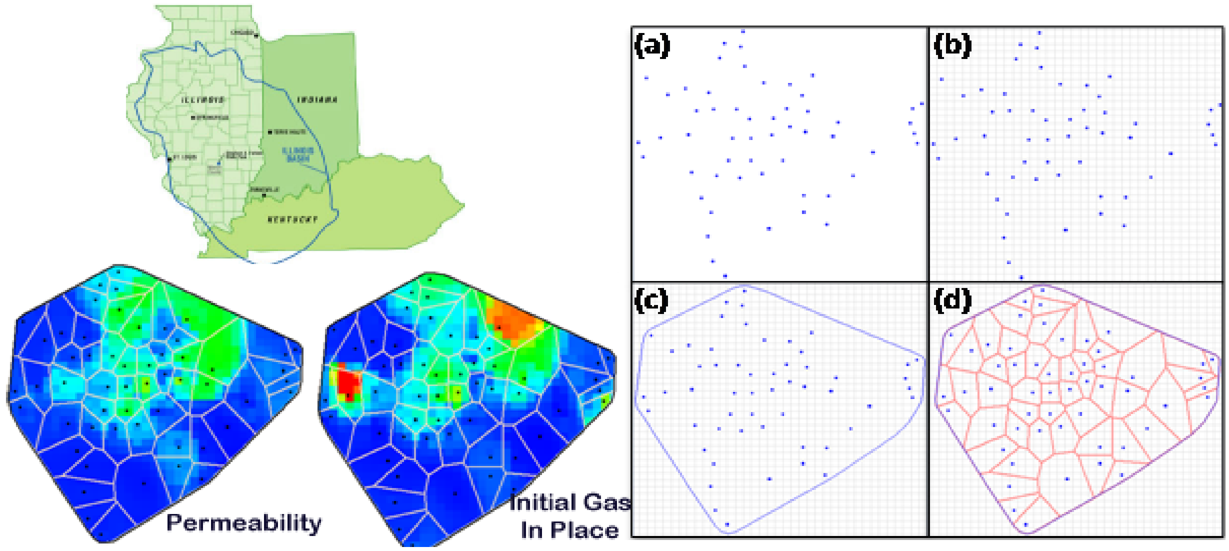

Figure 1. *Applying Top-Down Modeling to New Albany Shale (NAS). Steps involved in preparing the model.*

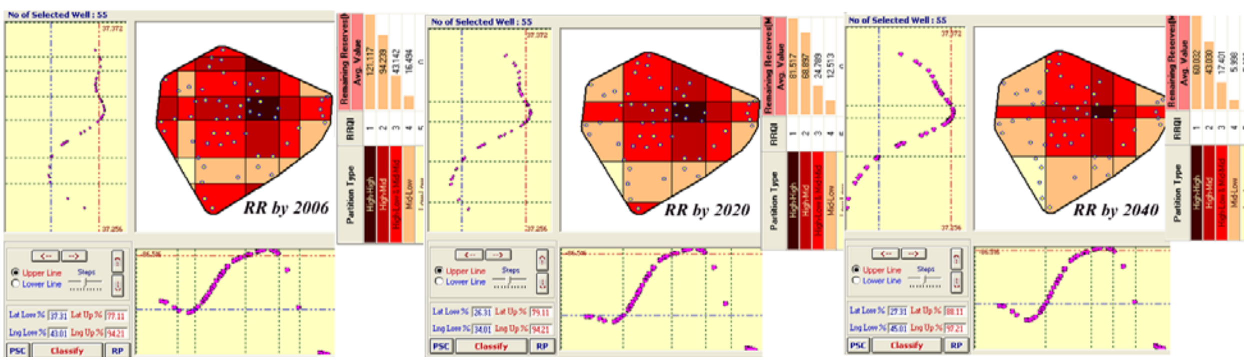

Figure 2. *Assessing Remaining Reserves as a function of time Using Fuzzy Pattern Recognition, NAS.*

Figure 2 shows the Remaining Reserves (RR) as a function of time till 2040 if no new wells are drilled. This is one of the last steps in the Top-Down modeling work flow. RR along with other outputs from the Top-Down modeling provides means for identifying the optimum locations for infill (new) wells. Production from infill wells is predicted and the RR under new circumstances are calculated and mapped similar to those in Figure 2. Regions shown in different colors in Figure 2 are explained in the following section.

APPLICATION OF TOP-DOWN MODELING TO LOWER HURON SHALE

Detail of Top-Down modeling application to Lower Huron Shale can be found in the SPE paper[2] dedicated to this study. Figure 3 shows using Fuzzy Pattern Recognition (as part of Top-Down Modeling) in order to identify the portions of the shale formation that has contributed the most to the production during the first three month, 1, 3, and 5 years. In this figure the reservoir is delineated into several RRQIs (Relative Reservoir Quality Index) shown in different colors. The portion of the reservoir that is shown with the darkest color represents RRQI of 1. This is the portion of the reservoir

[2] Fast Track Reservoir Modeling of Shale Formations in the Appalachian Basin. Application to Lower Huron Shale in Eastern Kentucky. O. Grujic & S. Mohaghegh, 2010 SPE Eastern Regional Conference & Exhibition. Morgantown, West Virginia.

that has made the largest contribution to production followed by RRQI 2, 3, 4. The colors of other RRQIs gradually get lighter until the region for RRQI 5 become almost white.

That contribution of these portions of the shale to production is calculated by taking into account the number of wells that are included in each of the RRQIs. Furthermore, these regions refers to depletion in the shale formation since locations that have has highest amount of production are, relatively speaking, the most depleted parts of the reservoir.

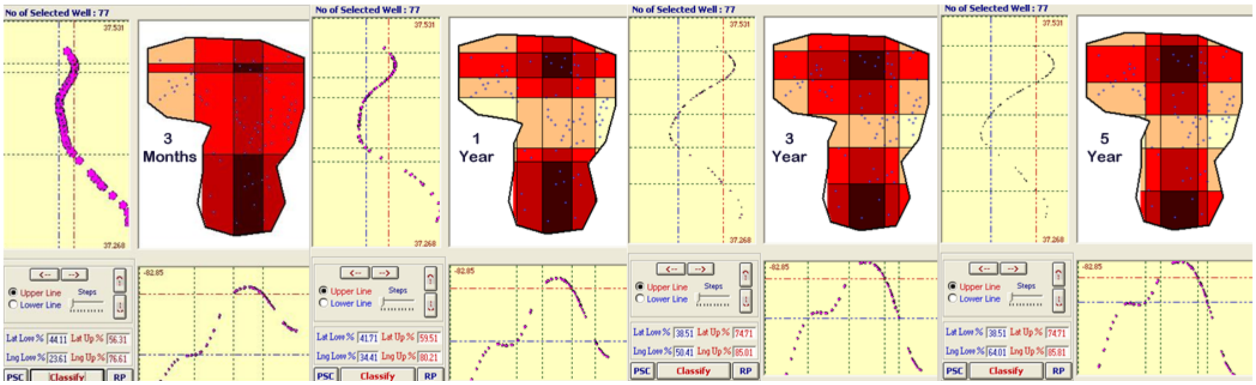

Figure 3. *Assessing Remaining Reserves as a function of time Using Fuzzy Pattern Recognition, NAS.*

APPLICATION OF TOP-DOWN MODELING TO MARCELLUS SHALE

Application of Top-Down modeling to Marcellus Shale is an ongoing study that will be completed and published in the near future. The Top-Down model is being developed for 298 wells that have been completed in the Marcellus Shale in West Virginia. Figure 4 shows the location of the wells in WV as well as the preparation of the model using the Cartesian and the Voronoi grid systems.

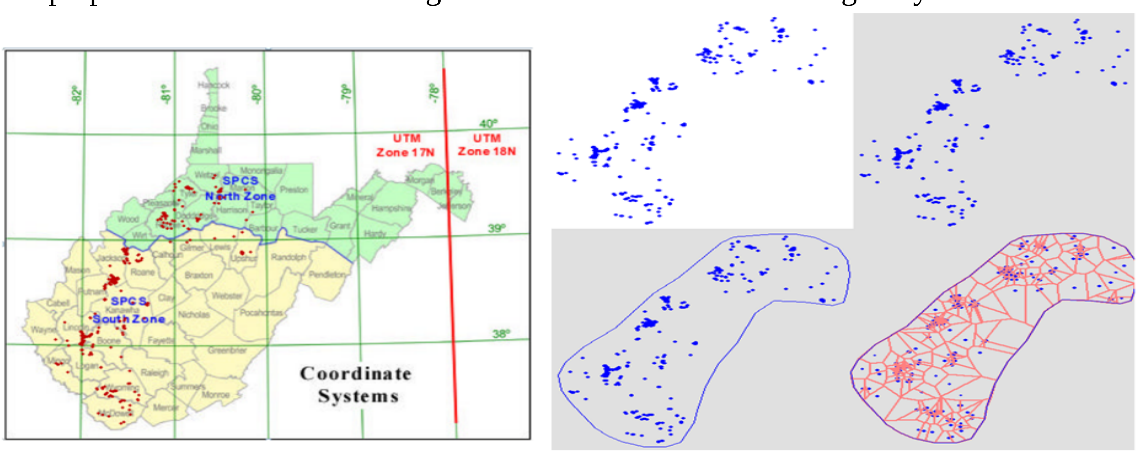

Figure 4. *Top-Down model being developed for 297 Marcellus wells in West Virginia.*