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Reservoir Characterization of Pennsylvanian Sandstone Reservoirs

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Objectives

The overall objectives of this work are : (i) to investigate the importance of various qualities and quantities of data on the optimization of water flooding performance; and (ii) to study the application of newly developed, geostatistical techniques to analyze available production data to predict future prospects of infill drilling.

Specifically, to satisfy our first objective, we will study the feasibility of applying fractal geometry concepts to characterize individual formations; develop a three-dimensional conditional simulation program to define reservoir properties at various scales; establish a method to integrate the data collected at various scales including the well test and the core data; and to investigate the utility of outcrop data in describing subsurface reservoir details. To satisfy the second objective, we will investigate various techniques to utilize the production data, including initial potential and the production decline, in proposing a possible location for a future infill well. The techniques investigated will include geostatistical and time-series analyses. The study will be restricted to Pennsylvanian sandstone reservoirs commonly found in Oklahoma.

Summary of Technical Progress

The technical progress is subdivided into several sections based on the tasks in the original project.

1. Collection of Data

The data collection phase is almost complete. The data are collected from the Burbanks and the Glenpool fields. Both fields produce from the Pennsylvanian Sandstone reservoirs. The depositional environments for both reservoirs is fluvially dominated deltaic environment. For our purposes of the study, we have selected part of the Burbanks field. This part contains approximately 200 producing wells. The reason for selecting this part was several wells in this area are drilled recently for polymer flooding purposes. As a result, these well contain modern well logs and core data. Such data are easy to interpret and developing reservoir description. We have collected all the available log and core data from all these wells. In addition, initial potential of majority of these wells is also obtained. For Glenpool field, we have collected a freshly cut core from one of the areas for further analysis. Additionally, core, log and production data will be made available from the same part of the field in few months.

2. Waterflooding Optimization

This section is subdivided into several sub-tasks and is discussed separately as follows:

A. Characterization using Fractals

The primary goal of this work is to study the feasibility of applying fractal geometry technique to characterize producing formations. The characteristic dimension to be investigated is called an intermittency exponent, H.[1] Several techniques are available to estimate the value of H based on the available data. These techniques include R/S analysis, spectral analysis, box counting method and the variogram analysis. A computer program is developed incorporating all these techniques to analyze the trace data. In addition, we have also incorporated a new technique, called as integral of variogram method, in the program.

To test the reliability of these various techniques, they need to be tested using synthetic data having known properties. A program is written to generate synthetic fractional Gaussian noise (fGn) and fractional Brownian motion (fBm) using a spectral analysis method. Using three types of distribution functions (normal, log-normal and uniform), one hundred traces of fGn were generated having different number of data points. The number of data points ranged from 20 to 5000. Four methods were used to analyze the synthetic data. These methods are variogram, integral of variogram, box counting and R/S analysis. The estimated values of intermittency exponents were compared with the input values of H.

Based on the comparison of the estimated and the input values of H, we observed that none of the methods are reliable for small number of data points (typically less than 50). For large number of data points, box counting and R/S analysis methods give reasonable results. However, above H value of 0.7, these methods under-predict the true value of H. The difference between the predicted and the input values of H becomes small as the number of points in the trace increase. For points greater than 500, both R/S and box counting method are quite reliable. In contrast, the variogram method consistently under-predicts the H value even for large number of data points. On the other hand, the integral of variogram method consistently over-predicts the H value. Both these methods are observed to be highly unreliable for the purposes of estimating the H value.

The next step will be to investigate the application of R/S and the box counting method using the actual well bore data. We will use the data from both the sandstone and the carbonate environments to investigate the applicability of H in identifying the type of depositional environment.

B. Three Dimensional Conditional Simulation

To describe the reservoir in three dimensions, we have selected a method of annealing. Originally proposed by Farmer,[2] the method is based on the principle of swapping randomly generated values having the same histogram as the sampled values. After every swap, a predefined energy function is calculated and compared with the energy function in the previous step. If the new function is smaller, the swap is accepted. If the new energy function is greater, the swap may still be accepted depending upon the probability function. The process of swapping will continue till a desired level of energy function is reached. The method is fast, flexible and allows incorporation of various constraints in generating the reservoir properties.

A three dimensional, conditional simulation program is developed. Currently the program allows two constraints; histogram of input data and the spatial relationships (defined by) in several discrete number of directions. The type of variogram functions allowed include the conventional such as spherical and exponential variograms and fGn and fBm functions which can be used to describe the fractal behavior.

The annealing program is currently being tested. We have generated synthetic data sets having known histogram and the spatial structure and compared the generated values with the input constraints. The match between the two is excellent. A preliminary study has also been conducted where a cross section between two wells is generated by using the information from those two wells. Log data from a third well, which is drilled between the two wells, is then compared with the simulated log data at the same location. The match between the two is quite good. The program has also been tested by generating a three dimensional description of a carbonate reservoir using well bore data from four wells. Three wells are located within the area from which log data are also available. The simulated data from the three dimensional description are compared with the actual data from these three wells. The match is quite good.

Currently the program is being optimized to run it more efficiently. Also data from some horizontal wells is currently analyzed to possibly provide guidelines in defining spatial variability in the horizontal direction.

C. Effective Properties for a Grid Block

Reservoir properties are measured on various scales. Core data are collected on a size of two inches, whereas the well test data are collected on a reservoir size of thousands of cubic feet. From simulation point of view, we are interested in determining the grid block properties. A typical grid block size may vary between ten to thousand feet in size.

We are investigating the estimation of an effective property of a grid block by using both analytical and numerical methods. On analytical side, we are developing a method of defining an effective tensor of a grid block containing heterogeneties. We are assuming that each grid block contains four smaller grid blocks each having different anisotropic permeability value. Using two different boundary conditions, an effective permeability of a grid block is estimated. The effective permeability is tensorial in form and contains non-zero non-diagonal elements. Preliminary comparison with a finite element simulator indicates a reasonable match between the analytical and numerical results.

In future, we would extend the analytical method to include tensorial small-scale heterogeneities which may be present in a larger grid block. Once a method is established, the suitability of a method can be tested using outcrop data which are measured on a relatively small scale.

3. Outcrop Studies

An outcrop has been selected for further studies. This outcrop is called a Blue Jacket sandstone and is located approximately 45 miles north-east of Tulsa. This outcrop contains the same Red Fork sand as the sand from which Glenpool field is producing. We are in the process of mapping the outcrop. The detailed mapping will allow us to identify the geological facies distribution. Based on the mapping, a systematic coring program will be developed.

At present, few sample cores have been taken and are analyzed. The property variation indicates that the geological controls have significant effect on the variation. Further, the cores from the outcrop are visually similar to the subsurface core taken from the Glenpool field. Further investigation will allow us to quantify the similarities in more details.

4. Infill Drilling

To develop a procedure to locate infill drilling prospects, we have decided to start with a synthetic reservoir. The main advantage of using a synthetic reservoir is that we do not have to be concerned with production and operational constraints imposed upon the actual production. Further, we can control drilling and location of the wells.

To generate a synthetic, but realistic, reservoir, we have used the data from the Burbanks field. We have selected part of the Burbanks field, approximately 1900 acres in size. After collecting the log and the core data from all the wells located in that part, we have identified the facies present at each well location. Total of ten facies could be identified.

Using the facies description, spatial relationship for each facie is developed. Using the core data, a semi-log relationship between permeability and porosity is developed for each facie. Using a method of conditional simulation, a three dimensional description of the reservoir is developed. For each gird block within the reservoir, a relationship between permeability and porosity is honored.

Using the synthetic reservoir description, wells are drilled over 160 acre spacing and using oil properties similar to Burbanks field, the reservoir performance is simulated over a ten year period. Primary results indicate that the simulated wells are producing at the same order of magnitude rates as the actual wells in Burbanks field at the beginning. This is an indication that our reservoir description is close to reality.

Using the simulations, we propose to analyze the data to predict possible in-fill locations within the reservoir. Several possibilities are currently being investigated. One possible approach is to use some type of inverse modeling where the production data along with the core and the log data can be used to define the reservoir description. Based on the reservoir description, and knowing the reservoir property values, possible in-fill locations can be determined. Another possibility is to use only production and core and log data and to use co-kriging approach to locate an area of the reservoir which has high productivity but low continuity. Both these approaches are currently being tested.

References

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2. Farmer, C.L. : "Numerical Rocks," paper presented at the joint IMA/SPE European Conference on the Mathematics of Oil Recovery, Robinson College, Cambridge University (July 25-27, 1989).