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Development Of Reservoir Characterization Techniques And Production Models For Exploiting Naturally Fractured Reservoirs

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Abstract

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For many years, geoscientists and engineers have undertaken research to characterize naturally fractured reservoirs. Geoscientists have focused on understanding the process of fracturing and the subsequent measurement and description of fracture characteristics. Engineers have concentrated on the fluid flow behavior in the fracture-porous media system and the development of models to predict the hydrocarbon production from these complex systems. This research attempts to integrate these two complementary views to develop a quantitative reservoir characterization methodology and flow performance model for naturally fractured reservoirs.

During the current reporting period, research has continued in an orderly fashion with most activities nearing completion. Activities associated with the characterization methodology, development of interwell description techniques and development of the naturally fractured reservoir simulator have been completed. In addition, a two-day Conference on Naturally Fractured Reservoirs was planned and held in Oklahoma City in June. This conference attracted participants working with naturally fractured reservoirs and provided a forum to exchange information related to efficiently exploiting naturally fractured reservoirs. Seventeen technical papers were presented at the conference.

The project has requested an extension to finalize project activities and prepare the final project report. As a result, this semiannual report provides a brief summary of activities during the current reporting period with the Final Report providing complete project details.

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Executive Summary and Introduction

Many existing oil and gas reservoirs in the United States are naturally fractured. It is estimated that from 70-90% of the original oil and gas in place in such complex reservoir systems are still available for recovery, provided new technology can be implemented to exploit these reservoirs in an efficient and cost effective manner. Enhanced oil recovery processes and horizontal drilling are two fundamental technologies which could be used to increase the recoverable reserves in these reservoirs by as much as 50%. This research is directed toward developing a systematic reservoir characterization methodology which can be used by the petroleum industry to implement infill drilling programs and/or enhanced oil recovery projects in naturally fractured reservoir systems in an environmentally safe and cost effective manner. It is anticipated that the results of this research program will provide geoscientists and engineers with a systematic procedure for properly characterizing a fractured reservoir system and a reservoir/horizontal wellbore simulator model which can be used to select well locations and an effective EOR process to optimize the recovery of the oil and gas reserves from such complex reservoir systems.

The focus of the research is to integrate geoscience and engineering data to develop a consistent characterization of the naturally fractured reservoir. During the current reporting period, a method is proposed to relate the elastic compliance to permeability of fractured reservoirs, models to obtain fracture properties from conventional well logs are finalized, and work has begun on a user's manual for the naturally fractured reservoir simulator. In addition, the Mewbourne School of Petroleum and Geological Engineering and the Oklahoma Geological Survey hosted a Conference on Naturally Fractured Reservoirs as a primary technology transfer activity.

Results and Discussion

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Task I. Characterize Fractured Reservoir Systems

A sugar cube model has been developed for relating the elastic compliance and the permeability of fractured reservoirs. Using the sugar cube model to compute the dry or drained properties of fractured rocks, the results of Brown and Korringa (1975) have been utilized to derive expressions for predicting the compliances of fractured rocks as a function of saturation.

Using the proposed approach yields several interesting observations. Contrary to years of popular misconception, Direct Hydrocarbon Indicators (DHI's) can be used for fractured reservoirs. This development opens a new window of exploration for fractured reservoirs. Surprisingly, this includes the application of S-waves to the detection of saturation changes in fractured reservoirs.

A new laboratory/field approach to the study of reservoir rocks is suggested in terms of the sugar cube model. The basic idea is to assume that permeability measurements give a representation of the connected fracture porosity within a rock. The connected porosity determined by permeability measurements is assumed to also control the elastic anisotropy due to the fractures. These ideas neglect some of the technical differences between flow and mechanical properties but offer a systematic approach to the study of elastic and flow properties.

The sugar cube model can be used to integrate seismic studies in the assignment of important reservoir parameters for fractured reservoirs. As a result, both engineers and geophysicists end up discussing the same parameters controlling the performance of fractured reservoirs.

Task II. Develop Interwell Descriptors of Fractured Reservoir Systems.

In previous progress reports, a self-consistent physical model based on the theory of O'Connell and Budiansky (1984) was reported as well as a model based on the Fuzzy Logic computer science technique. Both models use conventional well logs to obtain parameters that try to characterize fracture parameters that can be related to flow properties for use in numerical simulators. The O'Connell and Budiansky model uses a genetic algorithm to obtain the crack density (ε) and aspect ratio (α). Mavko, et al. (1998) have shown that once ε and α are known, crack porosity can be computed using:

$$\phi_c = \frac{4}{3}\pi\varepsilon\alpha \qquad (8)$$

A complete description of the O'Connell and Budiansky algorithm can be found in the January 2001 Semiannual Technical Progress Report and in paper SPE 67280 (Martinez, *et al*, 2001). The Fuzzy Inference System obtains a fracture intensity index and is described in the July 2001 Semiannual Technical Progress Report.

Both models were tested using a synthetic example and a field case where the level of fracturing was unknown. These applications were reported in a previous semi-annual progress report. During the current reporting period, efforts have focused on finalizing the computer models for use.

Task III. Develop Wellbore Models for Fractured Reservoir Systems.

This work is complete. The models have been implemented in the reservoir simulator and have been tested. Details have been provided in earlier semi-annual reports.

Task IV. Reservoir Simulator Development/Refinement and Studies.

This task has focused on developing a naturally fractured reservoir simulator for use in analyzing the performance of naturally fractured reservoirs. The effort has included the implementation of Evans' (1982) model for naturally fractured reservoirs into an existing homogeneous reservoir simulator. Because of its simplicity and the accessibility of its source code, BOAST-VHS available from the US Department of Energy (Chang) was selected and modified. The final version of the modified BOAST-VHS has been called BOAST-NFR. The name BOAST-NFR was selected to identify this new modification of BOAST in order to provide a direct relation of the BOAST source code to the naturally fractured reservoir application.

The original BOAST-VHS code was translated from FORTRAN to Visual Basic (VB) and implemented in macros in an Excel-VB environment. Several runs were performed to verify the results from the converted simulator code with the original simulator. This translation was undertaken to assist in providing a PC-based simulator that can be easily implemented without a major investment in computer hardware or software. The ability to use a simple spreadsheet application for data input and output will allow the user the ability to use the graphics capability of the spreadsheet software for visualizing the results, eliminating the need for a sophisticated graphics package.

After verifying the translated code, the simulator was modified to handle the fracture system. To accomplish this, the BOAST formulation was compared with Evan's formulation for a naturally fractured reservoir. It was found that the formulations were similar and equation discretization followed a similar process, except terms that contain the non-diagonal part of the fracture permeability tensor. The partial differential equations were solved using finite difference approximations in the same way BOAST equations were discretized. The modified version also uses an IMPES solution of the resulting set of linear equations. The simultaneous solution of pressure equations for the fracture and the matrix is handled using LSOR.

The modified simulator, BOAST-NFR, has the following capabilities.

1. Numerical simulation of oil and gas recovery by fluid expansion, displacement, gravity drainage, and imbibition mechanisms.
2. Rectangular grid-blocks with variable dimensions.
3. Zero transmissibility option (inactive grid blocks and faults).

4. Simulation of tilted reservoirs by specifying the elevations to top of grid-blocks.
5. Porosity and permeability distributions for matrix and fracture systems. For fracture permeability, simulator requires a full tensor.
6. Inter-porosity flow rate calculation for single and multiphase fluids using constant shape factors.
7. Different relative permeability and capillary pressure tables for matrix and fracture systems. One table for each system is needed.
8. Pore matrix and fracture compressibility as function of pressure.
9. Oil-water-gas PVT tables for reservoir fluids.
10. Bubble point pressure tracking scheme.
11. Pressure and saturation initialization for both porous media.
12. Automatic time-step control.
13. Option for automatic control of LSOR acceleration parameter.
14. Material balance check on solution stability.
15. Vertical, horizontal and slant wells with specification of rate or pressure constraints on well performance. Horizontal wells can be produced with different wellbore conductivity by using either infinite conductivity or uniform flux.
16. No restrictions regarding the number of iterations, gridblocks, and wells.
17. Additional or re-completion wells during the period represented by the simulation.

After completion of the simulator development, extensive testing was undertaken to verify the new simulator. This testing was described in the last semi-annual progress report for the period ending December 2001. A user's manual for the simulator is currently being developed.

Task V. Technology Transfer.

In June 2002, the University of Oklahoma hosted a two-day conference on naturally fractured reservoirs. The Conference on Naturally Fractured Reservoirs was held on 3-4 June 2002 in Oklahoma City and was organized by the Mewbourne School of Petroleum and Geological Engineering and the Oklahoma Geological Survey. Abstracts were solicited from industry, research, and academic groups with an interest in naturally fractured reservoirs to develop the technical program. The technical program had seventeen presentations and these technical papers were published in a CD-rom proceedings volume that was distributed to the participants. The conference was attended by 94 participants from eight US states and Canada. Those registered for the conference represented industry, government, and academia. The conference was sponsored by Anadarko Petroleum, Devon Energy, EOG Resources, Kerr-McGee, Marathon Oil, and Phillips Petroleum. A copy of the Proceedings will be submitted with this report.

In addition, the research team published or presented the following technical papers during the current reporting period.

Penuela,G., Hughes, R.G., Civan, F. and Wiggins, M.L.: "Time-Dependent Shape Factors for Secondary Recovery in Naturally Fractured Reservoirs," paper SPE 75234 presented at the SPE/DOE 13th Symposium on Improved Oil Recovery, Tulsa, OK, April 13-17, 2002.

Penuela, G., Civan, F., Hughes, R.G. and Wiggins, M.L.: "Time-Dependent Shape Factors for Interporosity Flow in Naturally Fractured Gas Condensate Reservoirs," paper SPE 75524

presented at the 2002 SPE Gas Technology Symposium, Calgary, Alberta, Canada, April 30 – May 2, 2002.

Penuela, G., Civan, F., Hughes, R.G. and Wiggins, M.L.: "Models for Interporosity Flow in Naturally Fractured Reservoirs," paper NFR-002 presented at the OU Conference on Naturally Fractured Reservoirs, Oklahoma City, OK, June 3-4, 2002.

Martinez, L. and Hughes, R.G.: "Fractured Reservoir Properties from Conventional Well Logs," paper NFR-008 presented at the OU Conference on Naturally Fractured Reservoirs, Oklahoma City, OK, June 3-4, 2002.

Brown, R.L.: "A General Model for Fracture Compliance and Permeability," paper NFR-009 presented at the OU Conference on Naturally Fractured Reservoirs, Oklahoma City, OK, June 3-4, 2002.

Chesnokov,E.M. and Brown, R.L.: "Frequency Dependence of Fractured Reservoirs," paper NFR-012 presented at the OU Conference on Naturally Fractured Reservoirs, Oklahoma City, OK, June 3-4, 2002.

Conclusion

During the current reporting period, work has focused on finalizing activities associated with the project tasks. Work has progressed on developing techniques for estimating fracture properties from seismic and well log data and modifying a naturally fractured reservoir simulator. The research has progressed in an orderly fashion. A project extension has been requested to allow the research team to complete their current tasks and write the final project report.

A Conference on Naturally Fractured Reservoirs was held during this reporting period. This symposium served as the major technology transfer activity for the project. The conference was very well received by both industry and academia and was a successful venue for the sharing of information related to exploiting naturally fractured reservoirs.

Research efforts during the next reporting period will focus on formalizing the techniques and models developed for inclusion in the final project report. The proposed techniques will provide a methodology for characterization of the reservoir system and yield parameters needed for the naturally fractured reservoir simulator.

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O'Connell, R.J., 1984: "A Viscoelastic Model of Anelasticity of Fluid Saturated Porous Rocks," Physics and Chemistry of Porous Media, AIP Conf. Proceedings, p.166-175.