Integrated Field Study of Heavy Oil Reservoirs using Integrated Geophysics, Geochemistry, and Numerical Modeling Techniques

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Summary

The complete reservoir characterization of cold production reservoirs involves the integration of geochemistry, geology, geophysics, and numerical modeling of reservoir production. This procedure should optimize enhanced oil recovery. The following talk describes progress of such integrated studies for a field study at Plover Lake, Saskatchewan.

Introduction

Heavy oil cold production is a non-thermal process in which heavy oil and sand are simultaneously extracted and produced by using powerful progressive cavity pumps. The simultaneous extraction of oil and sand generates high porosity channels termed “wormholes”. It is believed that the wormholes play an important role in heavy oil production due to their high permeability. The development of wormholes causes the reservoir pressure to fall below the bubble point, and the dissolved-gas comes out of solution to form foamy oil, causing a partially gas saturated reservoir. The goal of our research is to solve the challenging engineering problems of characterizing cold production reservoirs.

Methodology and Results

Our research includes systematic and comprehensive studies by using real seismic and well logging field data to monitor the wormhole and foamy oil in the reservoir. By using real field 4-D seismic data, multi-component seismic data and well logging data, we have conducted seismic inversions, time-lapse seismic analysis, seismic multi-component analysis and seismic amplitude analysis. Encouraging results have been achieved in our research; we have detected seismic amplitude anomalies and time shift anomalies which may be caused by wormholes and foamy oil. The results can be very useful and valuable to reservoir engineers as they can use our results to determine well spacing, to optimize infill drilling, and to plan production strategies in heavy oil cold production. The use of a 4-D velocity analysis is also a great tool for detecting and monitoring the wormholes and foamy oil since the seismic wave velocities are very sensitive to the changes in the reservoir porosity and fluid saturation. These velocities can also be used to monitor the behavior of the reservoir during the post cold production when using secondary recovery methods such as water flooding or thermal recovery."

Our understanding of the cold production effects in the reservoir has advanced through lab experiments, modeling studies, and the evaluation of field observations. Studies such as those presented by Lines et al. (2005) show that the combined effects of both wormholes and foamy oil could cause seismic amplitude anomalies and travel-time delays within the drainage regions in the cold production reservoirs. Rock physics studies (such as Chen et al., 2004), including laboratory measurements, are used to better understand how the seismic anomalies are related to reservoir changes. In addition to the analysis of seismic and rock physics data, a more complete understanding of reservoir production is achieved by the use of geochemical analysis. By using solvent extraction and solid phase separation of heavy oils followed by gas chromatography - mass spectrometry analysis (Fay et al., 2006), we can obtain detailed composition of petroleum. In this paper, we present a state-of-the-art case history study from Plover Lake, Saskatchewan. Geochemical core analysis from the Plover Lake Field shows two distinct sub-compartments of the reservoir based on composition. Allocating produced fluids to different depths in the oil column is possible using this approach. This information will be used in conjunction with the other researchers in the group to put together a comprehensive picture of the Plover Lake Field. We hope to correlate seismic anomalies with petroleum compositional trends by using advanced reservoir simulations in future work.

Elastic wave laboratory studies are also progressing at the U of Alberta Experimental Geophysics Group laboratory (ref. Qin and Schmitt, 2006). There have been a number of difficulties in obtaining appropriate signal through the highly attenuating samples, but these have been overcome to some degree by a redesign of the transducers employed. Modeling of visco-elastic responses that might be encountered have also been carried out.

While tremendous experimental and modeling studies have been devoted to understanding the anomalous behaviour exhibited by heavy oil reservoirs that are subjected to solution gas drive, there is still some uncertainty about the contribution of some of the rock and fluid parameters. The role of the micro-bubbles which are smaller than the pore size and can flow with the oil for example is amid these parameters that still under debate regarding their existence or their contribution in this process.

The current research examines the existence and flow of micro-bubbles and their contribution to heavy oil recovery. The theory of the micro-bubbles flow is examined by measuring the density of the flowing fluids as they exit the porous media. This work tackles this issue from a macroscopic scale by performing some depletion tests under different conditions to elucidate the role of micro-bubbles and whether or not they are important. Slow and fast depletion experiments were performed and the results arrived at by these tests were analyzed. The implications of these observations in modeling foamy oil flow are also presented. Both lab and numerical studies allow us to better understand the complexities of cold production.

Numerical modeling of such complexity is of particular interest to the field operators. Ideal predictions can assist oil producers to not only design better pumping schemes for sand control, but also optimize oil production and ensure wellbore stability. In this paper, the authors present an integrated modular approach to quantitatively predict sand production and enhanced oil recovery.

A modular approach is then adopted to effectively take advantage of the existing advanced standard reservoir and stress-strain codes. The model is implemented into three integrated computational modules, i.e. erosion module, reservoir module, and geomechanics module. The stress, flow and erosion equations are solved separately for each time increment, and the coupling terms (porosity, permeability, plastic shear strain, etc) are passed among them or iterated until convergence is achieved on a time step basis. Numerical results of field studies are presented to illustrate the capabilities of the model. The effects of foamy oil flow and sand production are also examined to demonstrate the impact on the enhanced hydrocarbon recovery. The model is ready to be used in conjunction with 4-D seismic to tune the erosion parameters and aid in the improvement of the seismic interpretation.

Conclusions and Plans for Future Research

The correlation between seismic anomalies and reservoir production data in cold production fields is very compelling. To better understand these correlations and the implications for enhanced oil recovery we have directed our research efforts toward integrated studies of geochemical, geological, geophysical, and reservoir production data. This research is leading toward a greater understanding of reservoir properties and should enhance production from heavy oil fields.

Acknowledgements

The authors gratefully acknowledge the financial support of this research from CHORUS (Consortium of Heavy Oil Research by University Scientists) and from NSERC (Natural Sciences and Engineering Research Council).

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