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The complex issue of fluid substitution in hot production of a heavy oil field: a facies-based approach

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Summary

Different fluid substitution models have been proposed trying to model the seismic behavior of heavy oil saturated rocks in cold and hot conditions. Apparent shear modulus of heavy oils in cold temperatures violates the assumptions of the Gassmann's theory. However, its simplicity convinced the authors to study its applicability and inaccuracy once again through careful evaluation of effective variables.

The studied reservoir is categorized into different facies classes from the genetic lithological point of view. Considering the saturating fluid(s), which might be gas, brine, heavy oil or any mixture of them, the purpose of this study is to apply a facies-based fluid substitution approach using well logs in order to model the observed time delays between the two time-lapsed seismic surveys.

Introduction

When it comes to reservoir production monitoring, especially for shallow unconsolidated reservoirs, 4D seismic monitoring has been accepted as a reliable practical method which has established its effectiveness through years of research and development (Chopra et al., 2010).

4D seismic monitoring is based all on rock physics and successful modeling of the seismic response of a mixture of interacting rocks and fluids. Rock physics provide a quantitative approach to evaluate seismic properties of porous media with different saturating fluids (Wang, 2001). Applicability of Gassmann fluid substitution model, as a famous and popular rock physics method, on cold heavy oils is under question due to the fact that the shear rigidity of cold heavy oils is non-zero (Han et al, 2008).

Theory and/or Method

The abundance of well data and dipole sonic logs in this field provided an invaluable data base for geophysical evaluation and verification of different rock physics models. The applicability of Gassmann's theory (Smith et al, 2003) in a particular case cannot be properly verified without correct assessment of the variables like mineral, dry rock and fluid bulk moduli denoted by K_0, K_{dry} and K_{fl} respectively. Another important parameter is porosity, φ.

P- and S-wave sonic logs along with routine petrophysical logs and evaluations can be used to construct a fluid replacement model and data points will be studied without considering their depth attribute.

The main parameter which defines the litho-facies from genetic facies in the studied reservoir is shale volume that is available as V_{sh} log / Fine Particle Volume (FPV) curve (Alam et al, 2015). Muddy/shaly facies and their fluid content will remain unchanged during production due to the impermeability factor. All other reservoir quality facies were examined at this study for fluid substitution model.

Reservoir pore pressure is generally low enough and hence, it let us to approximate k_{dry} from the bulk modulus of gas saturated sediments. On the other hand, filtering the data for very low porosity sediments allows us to predict mineral bulk moduli versus shale content. The proposed method is to apply different filter sets to extract seismic properties of rocks with various saturating fluids or at least constrain effective elastic moduli into narrower bands.

The effects of production on two nearby observation wells, prior to and after steaming will be compared and discussed.

Conclusions

Well log database is extremely helpful to understand the geophysical behavior of the reservoir media under different fluid contents and it is able to facilitate the fluid replacement workflow by better evaluation of K_{dry}, K_0 and K_{fl}. Facies based fluid substitution can increase the accuracy of the results while it makes the process practically simpler.

Since heavy oil reservoirs are generally unconsolidated shallow reservoirs, their seismic response is very sensitive to the fluid content. The effect of apparent shear modulus of heavy oil on seismic response of the reservoir and its magnitude can also be quantitatively assessed using well logs.

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