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Geomechanics in Reservoir Modeling – Role of 4D (Time-Lapse) Seismic

Shiladitya Sengupta* and N.C.Nanda**,
**Indian Institute of Technology, Kharagpur; Email: geoshila_iitkgp@yahoo.com*
***Petroleum Geophysicist (Consultant), former GM(Geop) ONGC; Email: ncnanda@yahoo.com*

Summary

Reservoir Geomechanics deals with rock deformation/ compaction of reservoir rocks with associated fluid flow. Depending on the nature of reservoir there may be compaction or subsidence or fractures due to the geomechanics of the reservoir. In addition to the known fracture categories: natural fractures (tectonic stress) and artificially induced fractures (drilling), a third category can be classified as fractures induced due to depletion of the reservoir. Deformation greatly changes the rock properties which control permeability. Hence, for effective reservoir modeling and simulation it is necessary that a solution to rock deformation and associated fluid flow be incorporated in the modeling. The elements of geomechanics controlling permeability can also be studied from integrated analysis of P-waves and S-waves (Poisson's ratio), Shear-wave components (Birefringence), and borehole sonic (Stoneley waves)

Introduction

Geomechanics and reservoir modeling essentially deals with the problems of compaction and or deformation of the reservoir rocks associated with fluid flow. During production from a hydrocarbon reservoir the formation pressure decreases and the effective stress increases resulting in the compaction/deformation of the reservoir rocks. Compaction can produce elastic or inelastic strains, affecting grain to grain contacts and thus the intergranular space, resulting in subsidence. In cases, where the reservoirs do not compact there maybe deformations which may cause microfractures, fissures and possibly new / activation of faults. The effects of these elements of geomechanics is likely to control azimuthal permeability and fluid flow in the reservoir. It is therefore immensely important that a solution to the problem of rock geomechanics and fluid flow be found in the process of reservoir modeling and simulation.

Abstract

Fracture mechanics in rocks due to Geomechanics can be taken as a third category (depletion-induced) in addition to the known fracture categories: natural fractures (tectonic stress) and artificially induced fractures (drilling).These depletion induced fractures like the other fractures can also be analyzed from 4D (Time Lapse) seismic data. Moreover 4C (component) seismic helps in analyzing the phenomenon of birefringence in shear waves for the study of fractures and their geometry. A conjugate study of P-waves and S-waves leading to analysis of Poisson's ratio can also be greatly helpful in providing information towards fractures and fluid saturation. Another useful technique to detect fractures (hence permeability) can be in the recording of Stoneley waves in a borehole.

Theory:

Geomechanics in reservoir modeling essentially deals with the problems of rock deformation and associated fluid flow. During depletion of a reservoir the pressure decreases and the effective stress increases, resulting in rock deformations. Rocks deform through a combination of elastic and inelastic strains, affecting grain to grain contacts. Reservoir compaction and resulting subsidence are examples of geomechanical behavior. In cases, where the reservoir do not compact the deformation may include microfractures, fissures, and possibly even minor faults. Fracture mechanics in rocks can be considered as a part of reservoir Geomechanics. The permeability of the reservoir to a large extent could be controlled by the effects of geomechanics and it is therefore important that its components be taken into account in the reservoir modeling and simulation.

The Geomechanics effects in certain favorable cases can be estimated from 4D seismic. Reservoirs under production undergo changes in pressure and fluid saturation. The changes affect velocity, density and Poisson's ratio of rocks and maybe detected by a 4D (Time lapse 3D seismic). Seismic changes indicated in 4D therefore can be related to dynamics of fluid flow and reservoir deformation.

The 4D is now increasingly used in reservoir monitoring (SRM), and helps in studying the elements of fluid flow surveillance, such as local water/gas conings, bypassed oil, permeability barriers, faults etc.4D is also being used in reservoir characterization, i.e., in estimating fluid saturation and effective porosity. While application of seismic as a fluid flow surveillance technique has been now established, we focus on the role of seismic in dynamic reservoir characterization by accounting the deformations caused by Geomechanics. This can be done by a 4C seismic technique where all the components of shear wave and the P-waves are measured. In the presence of anisotropy (which is invariably present in the reservoir) the deformations in the rocks caused by geomechanics can thus be studied by conjugate analysis of shear waves and P-waves.

Fracture is a loss of cohesion in a rock matrix, it includes joints, fissures, vugs and minor faults. Normal fractures owe their origin to tectonic stresses, whereas induced fractures are artificial, caused by drilling through the formations. Active fractures are cracks created by drill bit, but are connected to background fractures.

Deformation or fractures due to Geomechanics constitute a third category of fractures (production-induced).The fracture geometry plays a major role in permeability and hence in production of hydrocarbons. The important fracture parameters are density, frequency, orientation, and their geometry. Fractures can be identified by surface and borehole sonic logs.

In the presence of anisotropy, the two orthogonal components of shear waves S_H and S_V get differently polarized having different velocities (birefringence). Shear waves allows us to analyze this phenomenon and helps in estimating fracture parameters. Analysis of Poisson's ratio by conjugate study of P and S waves will also lead to info about fractures and fluid saturation.

Another useful technique to detect fractures can be the recording of Stoneley waves in a borehole. Stoneley waves are waves which propagate around boreholes as an expansion and rarefaction of the borehole wall. The amplitude of the waves get attenuated in the presence of fractures with energy attenuation proportional to the relative movement between viscous fluid and the solid matrix of the rock. The dissipation is controlled by the ease with which the fluid flows and consequently the study provides information about the most important parameter – Permeability. Stoneley wave's reflectance is preferred to that of P-waves and S-waves attenuation because it has higher energy content and is less dependant on lithology.

Conclusion

A third category of fractures, (depletion-induced), may be considered due to the reservoir geomechanics, which occur during the production of the reservoir. These fractures play a major role in the fluid flow dynamics of the reservoir and hence should be taken into account for better reservoir modeling and simulation. These fractures and their geometries can be studied from 4D seismic and sonic logs.

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