Using Geomechanics to Predict Stimulation and Production Response in Shale Gas Reservoirs

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Summary

An accurate geomechanical earth model (GEM) including constraints on stress magnitudes and orientations, mechanical rock properties, and the orientations and characteristics of natural fractures, is essential to understanding reservoir response to stimulation and production in low permeability reservoirs such as gas and oil shales. This is because in these reservoirs response is controlled largely by the properties of natural and induced fracture networks which are in turn controlled by the in situ stresses and by fracture distribution, width, stiffness and strength[1].

Characterizing stresses and natural fractures

The most commonly used methods to derive geomechanical models use as input elastic properties determined using a combination of conventional and crossed-dipole acoustic logs. However, these methods are based on overly simplified models for reservoir response to stress and deformation, and therefore require confirmation, typically using observations of stress-induced features (e.g., breakouts and drilling-induced tensile wall fractures) in image logs. Furthermore, identifying and characterizing fractures requires direct observation using either wellbore image data or core. Independent characterization of fracturing and stress derived from wellbore image analysis also makes it possible to differentiate the cause of seismic anisotropy (e.g., is it stress-induced or structural / fracture-induced?) often observed in surface seismic surveys. Regardless, accurate information on the distribution and orientations of natural fractures and on the magnitude and orientation of the in situ stresses is required in order to utilize geomechanics to understand and predict reservoir response to stimulation and production (see Moos and Barton, 2008).

Fracture control on conductivity

It is increasingly recognized that the most permeable natural fractures are often those which are optimally oriented to slip, i.e., are shear fractures, rather than those which have the lowest applied normal stress, i.e., Mode I fractures. When slip is induced on these fractures their aperture increases and their sensitivity to pressure decreases. In other words, slipped fractures are both more permeable and less susceptible to a decrease in conductivity with depletion.

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[1] Network connectivity also plays a role, which is not discussed in this paper.

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The pressure required to initiate shear slip on any fracture can be computed if stress magnitude and orientation, fracture orientation, and fracture strength are known. In general, and for many fracture orientations, the pressure required to induce slip is lower than the pressure required to open Mode I fractures. The broad zones of microseismicity often induced by stimulation, and the characteristic focal mechanisms of events, confirm that the increase in pressure can not only induce hydraulic fractures but it also can induce slip on pre-existing natural fractures which in turn results in an increase in their conductivity.

Figure 1 shows the influence of the stress state on the ability to stimulate natural fractures in a shale gas reservoir. The fracture properties (strengths, distributions, and orientations) are identical, but in the upper example there is a large difference in the two horizontal stresses, and in the lower example the two horizontal stresses are nearly equal and significantly lower than the vertical stress. When both horizontal stresses are low, nearly all of the fractures in this reservoir can be stimulated using pressures that are lower than the least principal stress. This is a situation in which long-term pumping at modest pressures is expected to significantly enhance reservoir permeability. On the other hand, if the maximum horizontal stress is closer to the vertical stress, only a subset of natural fractures can be stimulated before the injection pressure induces and propagates hydraulic fractures.

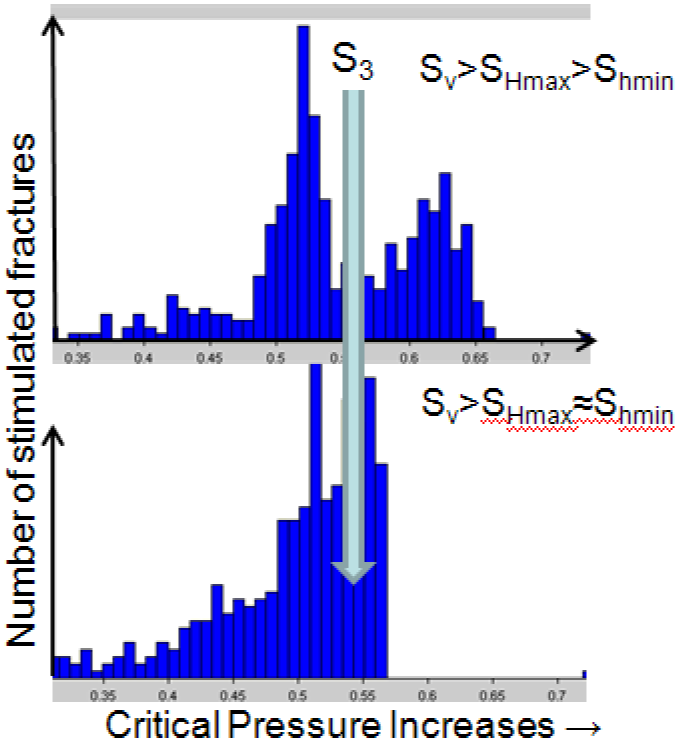

Figure 1: The pressure required to induce fracture slip in a typical gas shale is a strong function of the in situ stress state

It is not enough simply to be able to predict the onset of fracture slip. In order to deliver permanent improvements in reservoir performance by shear-enhanced stimulation, fractures which have slipped must have significantly higher permeabilities than those that haven't. Figure 2 illustrates a case in which fracture slip induces a permanent increase in conductivity. It models the effect of raising the reservoir pressure to from ambient (39 MPa) to slightly above 47 MPa. The upper plot shows a measure of well productivity; the lower plot is a histogram of the number of stimulated fractures as a function of injection pressure. The least principal stress is 52 MPa, so the pressure during the entire period of stimulation is always below that required to initiate a hydraulic fracture. Prior to the onset of slip on any of the fractures, productivity increases slowly with pressure, consistent with the fact that fractured reservoirs have pressure-sensitive permeability. Once fractures begin to slip, productivity increases rapidly. And, when the pressure is reduced at the conclusion of stimulation, the slipped fractures maintain their conductivity.

In order to utilize predictions based on this model in a quantitative way, it is necessary to know three things:

1. The magnitudes and orientations of the principal stresses
2. The distribution and strengths of natural fractures
3. The flow properties (aperture and stiffness) of fractures in their natural state and after they have slipped.

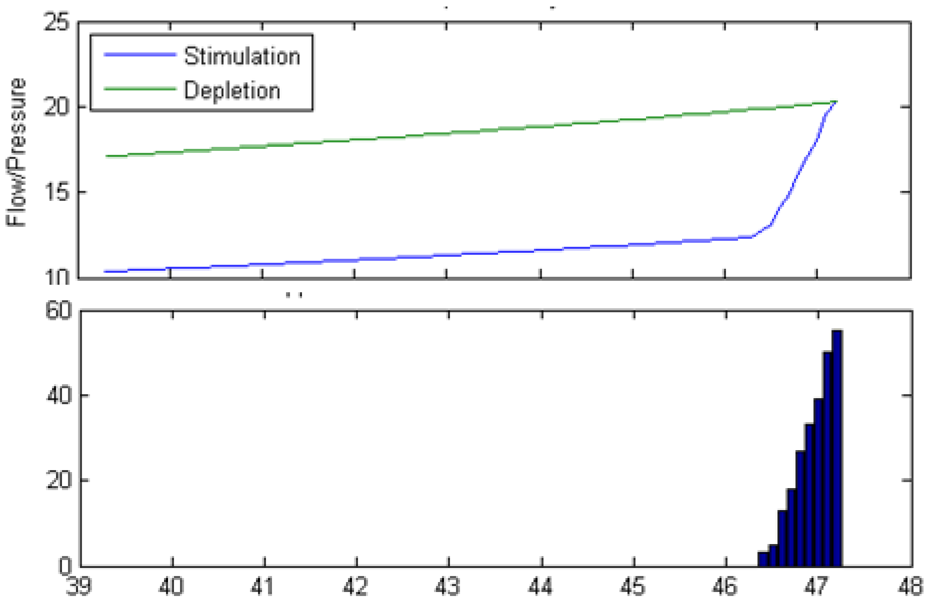

Figure 2. Effects of well stimulation at pressures below the least principal stress

Conclusions

Utilizing an approach to predicting gas and oil shale reservoir properties based on a model that has been used successfully to optimize well performance in many naturally fractured reservoirs, it is possible to model reservoir response to stimulation and production. Unfortunately, quantitative modeling requires reservoir and well test flow simulation. However, even in the absence of such analyses it is possible to predict based on stress state and fracture properties such things as the geometry of a stimulated region as a function of pressure. Stimulation effectiveness can also be estimated if natural fracture conductivity before and after slip are known. With this information, it is then possible to predict where slick-water stimulation is likely to create a broad stimulated zone, and where it is not.

References

Moos, D. and C.A. Barton, Modeling uncertainty in the permeability of stress-sensitive fractures, ARMA 2008, San Francisco, CA, July 1-3, 2008