Geophysical Research Abstracts
Vol. 14, EGU2012-3812, 2012
EGU General Assembly 2012

Effect of rock rheology on fluid leak- off during hydraulic fracturing

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In this communication, we evaluate the effect of rock rheology on fluid leakoff during hydraulic fracturing of reservoirs. Fluid leak-off in hydraulic fracturing is often nonlinear. The simple linear model developed by Carter (1957) for flow of fracturing fluid into a reservoir has three different regions in the fractured zone: a filter cake on the fracture face, formed by solid additives from the fracturing fluid; a filtrate zone affected by invasion of the fracturing fluid; and a reservoir zone with the original formation fluid. The width of each zone, as well as its permeability and pressure drop, is assumed to remain constant. Physical intuition suggests some straightforward corrections to this classical theory to take into account the pressure dependence of permeability, the compressibility or non-Newtonian rheology of fracturing fluid, and the radial (versus linear) geometry of fluid leakoff from the borehole. All of these refinements, however, still assume that the reservoir rock adjacent to the fracture face is nondeformable. Although the effect of poroelastic stress changes on leak-off is usually thought to be negligible, at the very high fluid pressures used in hydraulic fracturing, where the stresses exceed the rock strength, elastic rheology may not be the best choice. For example, calculations show that perfectly elastic rock formations do not undergo the degree of compaction typically seen in sedimentary basins. Therefore, pseudo-elastic or elastoplastic models are used to fit observed porosity profiles with depth. Starting from balance equations for mass and momentum for fluid and rock, we derive a hydraulic flow equation coupled with a porosity equation describing rock compaction. The result resembles a pressure diffusion equation with the total compressibility being a sum of fluid, rock and pore-space compressibilities. With linear elastic rheology, the bulk formation compressibility is dominated by fluid compressibility. But the possibility of permanent, time-independent (plastic) rock deformation significantly increases the pore space compressibility (compaction), which becomes a leading term in the total compressibility. Inclusion of rock and fluid compressibilities in the model can explain both linear and nonlinear leakoff. In particular, inclusion of rock compaction and decompaction may be important for description of naturally fractured and tight gas reservoirs for which very strong dependence of permeability on porosity has been reported.

Carter R.D. Derivation of the general equation for estimating the extent of the fractured area. Appendix I of “Optimum fluid characteristics for fracture extension”, Drilling and Production Practice, G.C. Howard and C.R.Fast, New York, New York, USA, American Petroleum Institute (1957), 261-269.