A simplified model to evaluate the effect of fluid rheology on non-Newtonian flow in variable aperture fractures

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1. Applications in reservoir engineering of non Newtonian fluids

Modeling of non-Newtonian flow in fractured media is essential in hydraulic fracturing operations, largely used for optimal exploitation of oil, gas and thermal reservoirs. Complex fluids interact with pre-existing rock fractures also during drilling operations, enhanced oil recovery, environmental remediation, and other natural phenomena such as magma and sand intrusions, and mud volcanoes.

Exploitation of oil/gas reservoirs:
polymer solutions

Fracturing fluids:
98% fresh water and sand, with chemical additives comprising 2% or less of the fluid. Shear-thinning (pseudoplastic) fluid are usually adopted.

Mining Engineering:
drilling muds (suspensions of solid particles), polutants with complex rheology

Exploitation of oil/gas reservoirs:

The nonlinear relationship between shear stress and shear rate

\[ \tau = \eta(1/n) \dot{\gamma}^n \]

is the Ostwald de Waaloe equation.

Largely used for optimal exploitation of oil, gas and thermal reservoirs. It produces fractures in the rock formation that stimulate the flow of natural gas or oil, increasing the volumes that can be recovered. Fractures are created by pumping large quantities of fluids at high pressure down a wellbore and into the target rock formation.

Once the injection process is completed, the internal pressure of the rock formation causes fluid to flow through the surface towards the wellbore. This fluid is known as "backflow" and "produced water" and may contain the injected chemicals plus naturally occurring materials such as brines, metals, radionuclides, and hydrocarbons.

A first step in the modeling effort is a detailed understanding of flow in a single fracture, as the fracture aperture is typically spatially variable. The equivalent flow aperture for non-Newtonian fluids of power-law nature in single, variable aperture fractures has been obtained in the past both for deterministic and stochastic variations.

Flow in a variable aperture fracture

The fracture aperture (\( b \)) is usually taken to vary as a 2-D, spatially homogeneous and correlated random field, with a probability density function \( f(b) \).

The in-th channel in each regime \( j \) (\( j = 1-3 \)) has width \( W_i = W_0b^k \).

The nonlinear rheological behaviour and the aperture spatial variability jointly have a significant impact on flow rates and spatial distribution (channeling effects); this in turn influences reactive transport (adsorption) and chemical reactions.

Flow parallel to constant aperture channels, i.e. transverse to aperture variation

The pressure gradient is transverse to the aperture variability

\[ p_x = f(0) - p(L)/L \]

The fracture model is discretized into \( N \) neighboring channels, each having equal width and constant aperture \( b_0 \).

References


Siliman, S.E. An interpretation of the difference between aperture estimates derived from hydraulic and tracer tests in a single fracture, Water Resources Research, 1988, 25(10), 2275-2283.