Upscaling of Water Floods in Fractured Reservoirs via the Fracture-Matrix Flux Ratio Estimated by Well Testing

[1]MATTHAI, S.K.*, [2]GEIGER, S. AND [1]BELAYNEH, M.

[1]Centre for Petroleum Studies, Earth Science & Engineering, Imperial College London, UK

[2]Institute of Petroleum Engineering, Heriot-Watt University, Edinburgh, UK

Hecto-metre scale sub-volumes of fractured oil reservoirs contain thousands of fractures with highly variable flow properties, dimensions and orientations. This complexity precludes direct geometric incorporation into field scale multiphase flow models. Macroscopic laws of their integral effects on multi-phase flow are required.

We have inspected multiphase flow in numerical simulations on fracture trace map-based three-dimensional discrete fracture models. Our results indicate that grid-block scale relative permeability, the time to water breakthrough, and the subsequent water cut primarily depend on the fracture-to-rock matrix flux ratio, q_f/q_m, quantifying the proportion of the cross-sectional flux that occurs through the fractures. This is a tensorial property readily determined by steady-state calculations of the partitioning of single-phase flow between fractures and rock matrix at far-field fluid-pressure gradients acting parallel to the coordinate axes of the discrete fracture model. Relative permeability during imbibition and drainage can be closely approximated by

$$kr_o(s_w) = \mathrm{erfc}\left(\frac{s_w}{\phi_f}\right) + \left(\frac{1-s_w}{q_f/q_m}\right), \quad kr_w(s_w) = \mathrm{erf}\left(\frac{s_w}{\phi_f}\right) - \left(\frac{1-s_w}{q_f/q_m}\right)$$

where ϕ_f is the fracture-related porosity. Hysteresis is so extreme that kr_o becomes similar to kr_w in primary drainage runs. Since ϕ_f typically is only a fraction of a percent, a cross-over from $kr_w < kr_o$ to $kr_w/kr_o \approx q_f/q_m$ occurs after the first few percent of recovery, and because q_f/q_m ranges between 10-1,000, sweep efficiency ignoring the positive influence of counter-current imbibition is extremely low. The up-scaled fractional flow function $f_o(s_w)$ derived from these relative permeabilities is convex with a near-infinity slope at the residual water saturation. This implies that the up-scaled spatially averaged Buckley-Leverett equation for fractured porous media does not contain a shock and a long leading edge characterises the water saturation profile resulting from imbibition. It captures the progressively widening saturation front and early water breakthrough observed in the discrete fracture reservoir analogues.

Prediction accuracy of fractured-reservoir performance by the proposed $f_o(s_w)$ up-scaling methodology depends on how well ϕ_f and q_f/q_m can be constrained under *in situ* conditions. The second topic of this presentation therefore are synthetic well tests conducted on fractured reservoir analogues for which q_f/q_m is known. Herewith we explore how accurately this ratio can be inferred from pressure derivatives. We also compare interpretations made from normalized pressure / pressure derivative curves from synthetic well-tests carried out on discrete fracture numerical models with their actual bulk properties as determined by another suite of numerical experiments. Regarding fluid-solid interactions, this analysis takes into account the response of the fractures to fluid pressure changes. It is controlled by fracture length and the strength of the rock matrix and can dominate the total systems compressibility in low porosity fractured reservoirs.

* Stephan K. Matthai, Dr., Earth Science & Engineering, Imperial College London, South Kensington Campus, South Kensington, SW7 2AZ, UK, +44 20 7594 7349, +44 20 7594 7444, s.matthai@imperial.ac.uk