Fracture-Matrix Flow Partitioning and Cross Flow: Numerical Modeling of Laboratory Fractured Core Flood

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Abstract

Naturally fractured reservoirs account for approximately 60% of oil remaining reserves worldwide [1]. The contrast between the hydro-mechanical behavior of the matrix and fracture network systems in fractured reservoirs results in complex flow regimes and partitioning of flow between the fracture and the matrix systems [2]. In-situ stress regime in the vicinity of the reservoir, which may change with its depletion profile, has a strong controlling influence on flow partitioning. There are currently no standard laboratory procedures for flow partitioning studies in fractured cores as are currently available for conventional non-fractured core flood studies and current procedures are yet unreliable. Hence the need to fully integrate laboratory studies with numerical simulations. Fracture flow, Darcy law and free and porous media flow physics interfaces of COMSOL Multiphysics subsurface flow module have been used in simulating a fractured core flooding test data to achieve a better understanding of fracture-matrix flow partitioning. The fracture flow interface was used along with Darcy Law due to the capability to create fracture as a boundary within the model geometry (Figure 1). Pressure boundaries were implemented and flow rate contributions of fracture and matrix were monitored at the outlet. Darcy flow equation was solved for the matrix while fracture flow physics was used for the fracture. Flow contributions of fracture and matrix were monitored through velocity vector surface integration on the matrix outlets and a modified line integration on the fracture outlet. Alternatively, free and porous media flow interface was applied to analyze how the cross flow changes under various stress levels. Cross flow measurement demands implementation of fracture as a volume in the geometry; the result of which is a large aspect ratio between the fracture aperture (in microns) and the matrix (few centimeters) dimensions. The direct results of large aspect ratio are a complex mesh and less memory efficient solver. The advantage of symmetry along with direct solver configuration was taken to overcome the convergence problems in re-meshing stages. In order to minimize the truncation error and maintain the solution consistency, a mapped mesh was used in combination with the mesh sweep functionality (Figure 2). Results show that the magnitude of flow partitioning decreases with increasing overburden stress although there were significant discrepancies in the magnitudes obtained from the two physics - fracture and free and porous media interfaces - used in the simulations (Figure 3). However, comparison of the simulated cumulative flow rates with experimental data shows a very promising match within an error range of 10-15 percent. The amount of cross flow between the matrix and the fracture also varied with stress loading. The use of pressure and velocity contours enabled the monitoring of flow paths within the fractured space (Figure 4). This study has demonstrated the need for integration of numerical

simulations with experimental studies to fully characterize flow in fractured reservoirs and evaluate quantitatively the flow partitioning phenomenon.

Reference

1. Mohamed Ahmed Elfeel et al., Upscaled multi-phase flow properties of fracture corridors, Paper SPE 139463 presented at the SPE Caspian Carbonate Technology Conference, Atyrau, Kazakhstan, 8-10 November (2010). DOI: 10.2118/139463-MS.
2. Susan M. Agar et al., The impact of hierarchical fracture networks on flow partitioning in carbonate reservoirs: examples based on a Jurassic carbonate ramp analogue from the High Atlas, Morocco, Paper SPE 135135 presented at the SPE Annual Technical Conference and Exhibition, Florence, Italy, 19-22 September (2010). DOI: 10.2118/135135-MS.

Figures used in the abstract

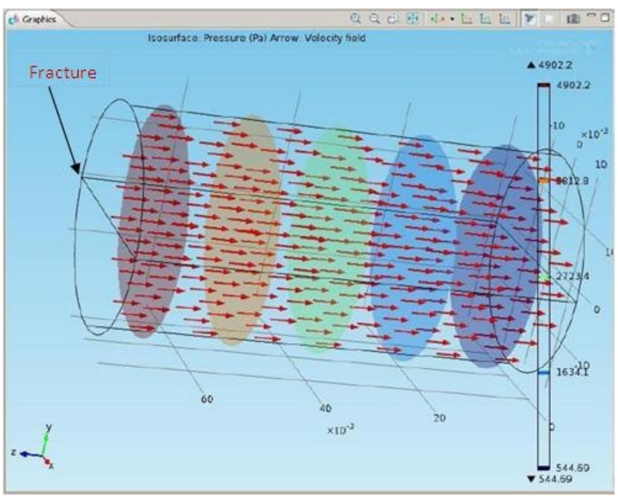

Figure 1: Longitudinal fracture introduced to the geometry as a boundary within the cylindrical core plug.

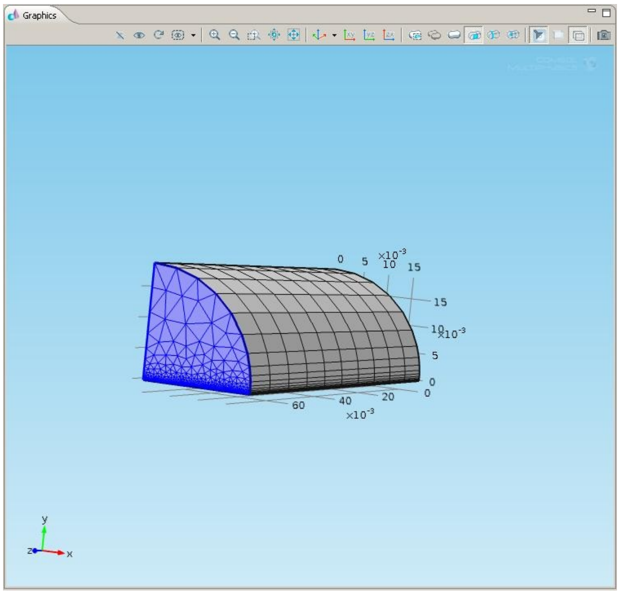

Figure 2: Dense meshing in the proximity of the fracture volume.

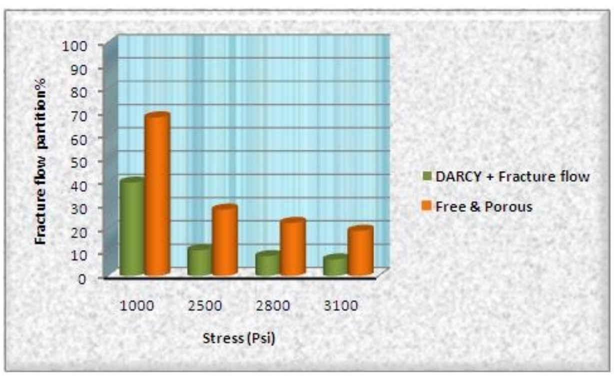

Figure 3: Fracture flow partitioning variation with respect to the overburden stress levels using two different Comsol interfaces.

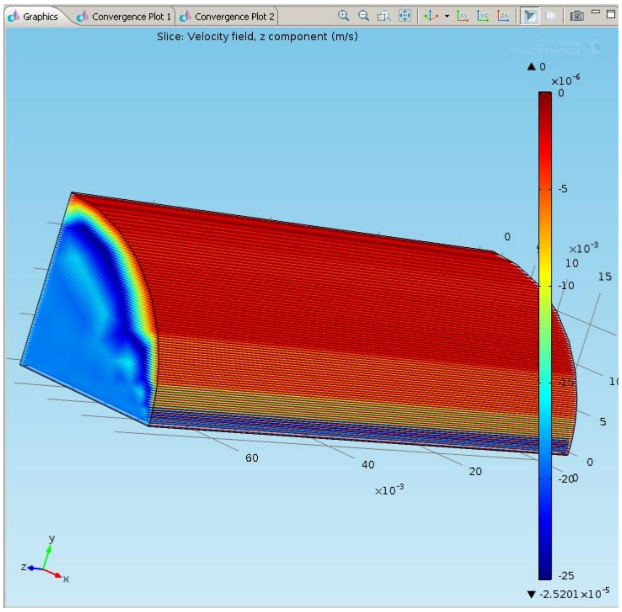

Figure 4: Z velocity spectrum in the porous core plug. Note the increase in the velocity (cross flow) as the fluid crosses the core into the fracture volume.