3D Modelling of Fracture Flow in Core Samples Using µ-CT Data

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Abstract

Introduction: Knowledge on flow behavior in fractured reservoir rocks is of great interest in petroleum engineering as well as for geothermal assets. The typical aperture of fractures in deep reservoirs is in the range of µm, while the whole reservoir can show lateral extensions of kilometers. Due to this big difference of magnitude, modeling of discrete fracture flow is not practicable on the reservoir scale, so a Darcy (or Brinkman) approximation has to be found. The key task is to find proper permeability values for the different zones of the reservoir. The approach of the present study is to model discrete fracture flow in core samples of 2-3 cm diameter and 4 cm length to assess equivalent directional permeability values and compare them to laboratory measurements. The distribution of fractures in the core samples was assessed using µCT (Micro Computed Tomography), where similar to CT used in medicinal application multiple X-ray images of one sample are recorded to reconstruct a 3D image of the fracture distribution with a resolution in the range of about ten to hundred µm, depending on the size of the sample. Data preparation: The 3D images were segmented and binarized using different image processing techniques, a suitable data volume in the shape of a cube was selected and meshed using the open source MATLAB® based mesh generation toolbox "ISO2MESH" [1]. In the next step the generated mesh was converted to a COMSOL-readable MSC NASTRAN™ file using Gmsh© [2]. The resulting tetrahedral mesh represents the connected fractures of the sample (Figure 1). Use of COMSOL Multiphysics: COMSOL Multiphysics' Laminar Flow physics interface was used to model fracture flow. The flow is induced through a pressure difference on two opposing boundaries using a "constant pressure boundary condition". Evaluation of the resulting flow is used to derive permeability values for the three special dimensions (see equation in Figure 2). To enhance stability and convergence of the steady-state solver a transient solution was calculated in advance to get consistent initial values. The total flow through the model (see Variable 'Q' in Figure 2) is the integral of the velocity over the cross-sectional area. Assuming an incompressible flow, the total flux Q is a conserved quantity and can be evaluated statistically through averaging in multiple slices. Furthermore the permeability can be evaluated using different dynamic viscosity values (e.g. air, water, crude oil, etc.).
Results & Outlook: The primary results of the present study are permeability values for the core samples according to the three space dimensions. The results will be validated via laboratory measurements of the corresponding samples. Additionally we will be able to analyze the discrete

flow paths and pressure variation inside the model. The final goal is to find a method for upscaling the so-achieved results to reservoir size and derive universally valid conclusions for the fluid flow in fractured reservoirs.

Reference

1. Qianqian Fang and David Boas, "Tetrahedral mesh generation from volumetric binary and gray-scale images," Proceedings of IEEE International Symposium on Biomedical Imaging 2009, pp. 1142-1145, 2009.
2. C. Geuzaine and J.-F. Remacle. Gmsh: a three-dimensional finite element mesh generator with built-in pre- and post-processing facilities. International Journal for Numerical Methods in Engineering, Volume 79, Issue 11, pages 1309-1331, 2009.

Figures used in the abstract

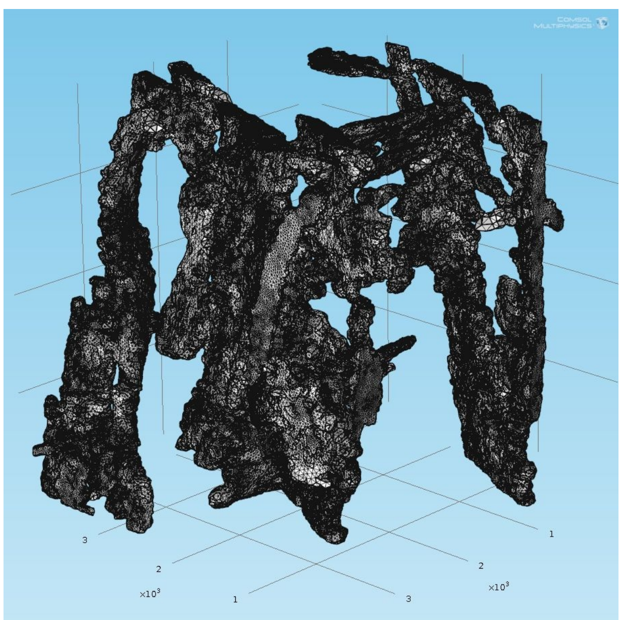

Figure 1: Tetrahedral mesh (approx. 1.02 million elements) that forms the basis for modeling.

$$K = \frac{Q \cdot \eta \cdot l}{\Delta p \cdot A}$$

Figure 2: Permeability as a function of the flow rate, dynamic viscosity, length, pressure difference and the crosssectional area.