Influence of Fracture Roughness on Flow Patterns and Transport Behaviour

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1. Overview

In simulations of multi-phase fluid flows through fracture networks in porous media, one of the first important steps is to investigate the influence of the fracture morphology on the hydrodynamic properties and transport behaviour (i.e., flow rates and breakthrough curves).

We compare the difference between smooth-walled fractures and real rough-walled fractures by simulating 1-phase flow through a single fracture. At the first stage we assume a 2-dimensional fracture geometry with an overlying aperture distribution. The subsequent simulations are used to reduce the parameters in the model by assuming a uniform permeability.

Several approaches are considered and compared to the complex permeability distribution simulation. In the next steps we will compare our numerical simulations to laboratory experiments. This will allow us to derive guidelines for approximating single fractures with a reduced number of parameters.

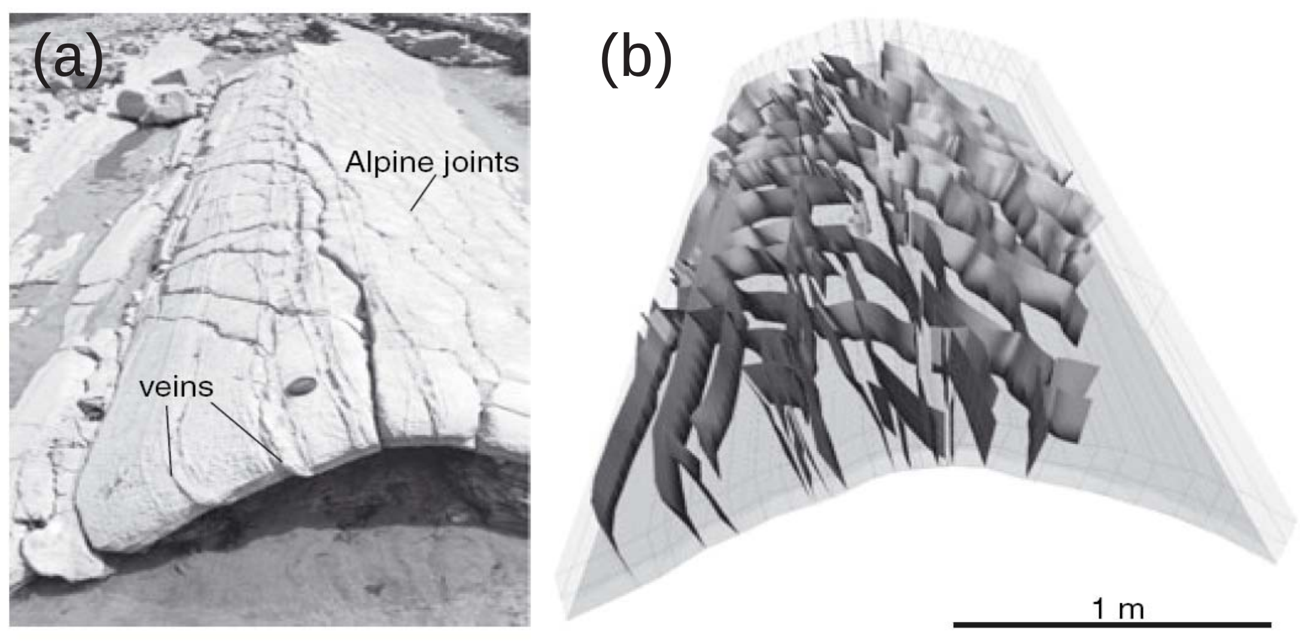

Figure 1. (a) Geologic complexity of an outcrop of Liassic limestone on the southern Bristol Channel, (b) free-form NURBS CAD model of the same structure (by Paluszny et al. 2007).

2. Statistically Generated Aperture Distribution

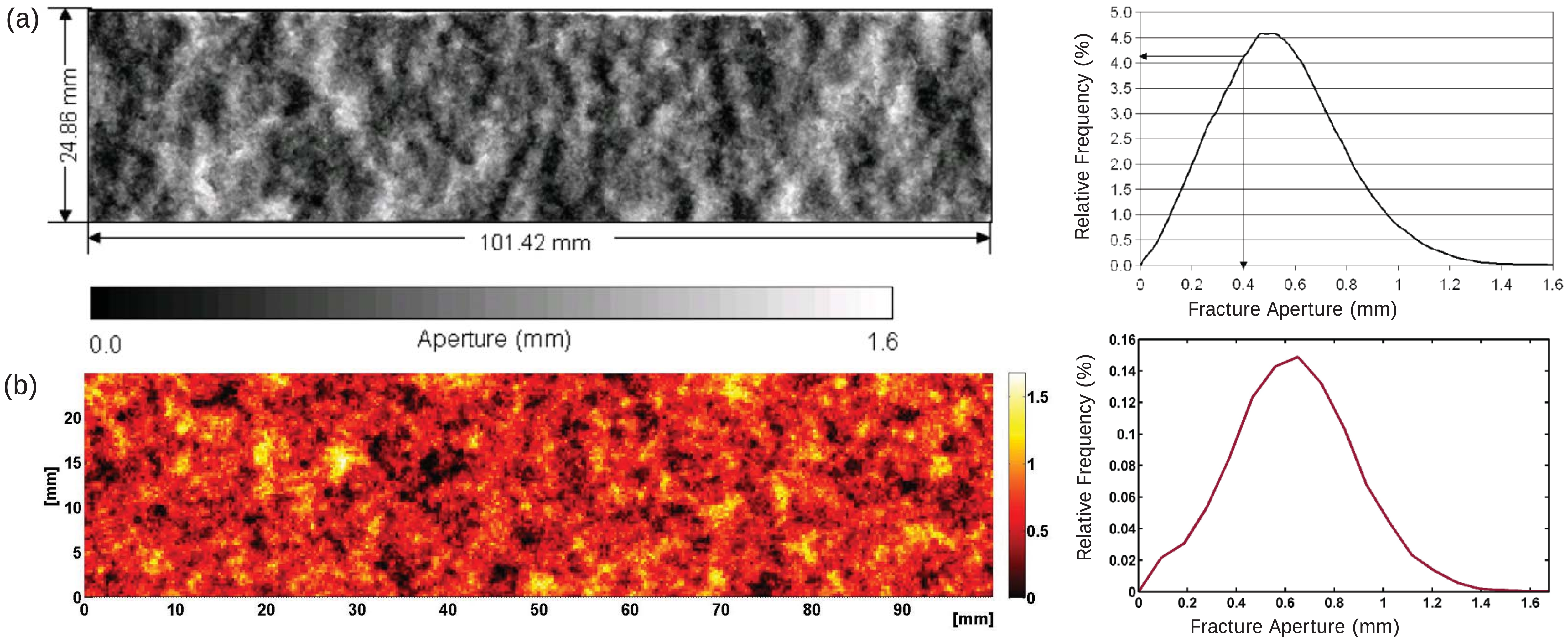

Figure 2.
(a) Real Fracture measured with High Resolution Computer Tomography (by Karpyn et al. 2008), min. aperture 0 mm, max. aperture 1.6 mm, mean aperture 0.58 mm, standard deviation 0.25 mm.

(b) Statistically generated fracture with the same statistical values.

The two diagrams on the right show the qualitative accordance of both fractures via their relative frequency maps of the fracture aperture.

3. Flow Simulations with CSMP++

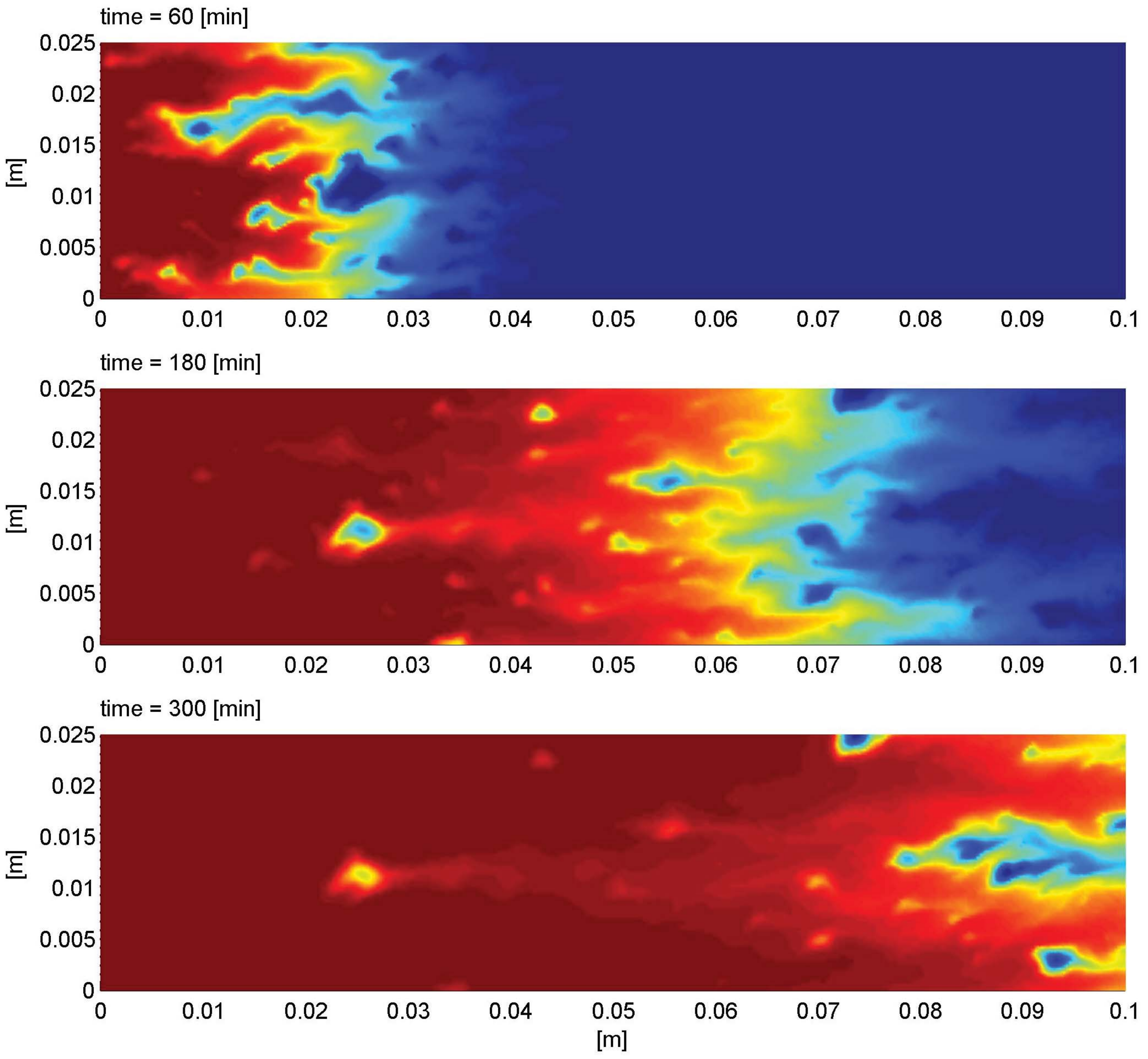

Figure 3. Flow Simulation for Concentration of a tracer through the statistically generated fracture in Fig. 2 (b) at different time steps. The flow is from left to right. Initially, the concentration in the fracture is zero. Fluid with high concentration enters at the left boundary. We simulated advection and dispersion, assuming that the fracture permeability scales with the cube of the fracture aperture. Red colors represent high concentrations and blue low concentrations.
Realisation with CSMP++ (Complex Systems Platform, developed at Imperial College London, ETH Zurich and Heriot-Watt University).

5. Future Work

- First 3D data acquisition using the newly built ECOSSE CT scanner to image dry carbonate core samples (see Figure 5)
- Additional simulations of a 2D fracture plane embedded in a 3D porous media to account for fracture-matrix transfer
- Implementation of 2-phase flow in computational model
- Compare simulation results for 1- and 2-phase flow with real flooding data from 3D computer tomography experiments
- Simulation of fluid flow through complex fracture networks (reservoir simulation)

4. Uniform Permeability Models

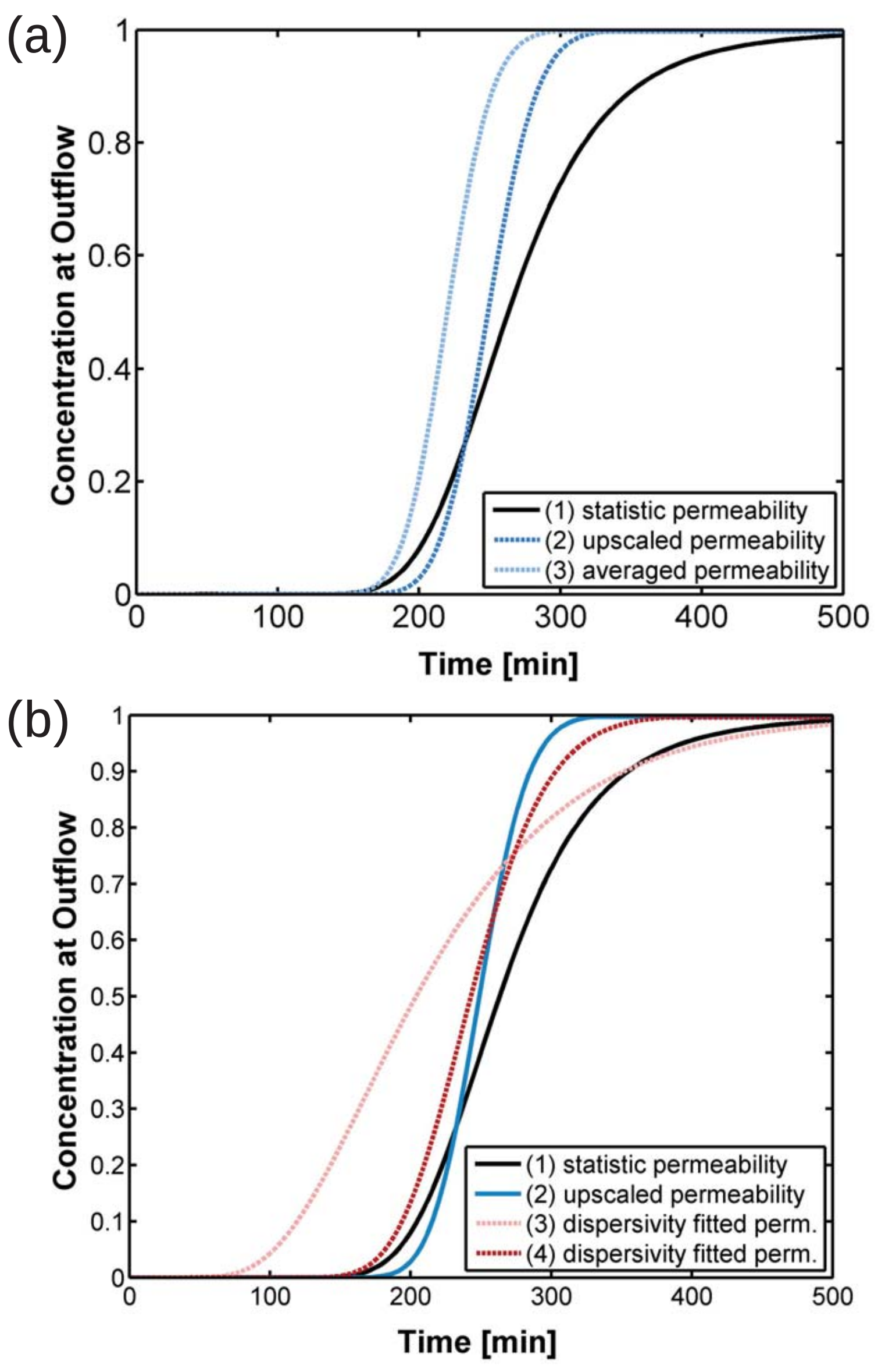

Figure 4.
(a) Breakthrough curves showing the concentration at the right boundary for different permeability models: (1) statistically generated fracture with an overlying permeability distribution, (2) fit with uniform upscaled permeability using the Cubic Law, (3) fit with uniform mean permeability.

(b) Improved fits for the upscaled breakthrough curves: (1) statistically generated fracture, (2) uniform upscaled permeability using the Cubic Law, (3) and (4) fit with uniform upscaled permeability and two additional parameters in the Dispersivity Tensor (longintudinal and transversal dispersivity coefficients a1, a2), (1) and (2) a1 = 3.e-5 m, a2 = 3.e-6 m, (3) a1 = 1.e-2 m, a2 = 2.5e-4 m, (4) a1 = 1.e-3 m, a2 = 1.e-5 m.

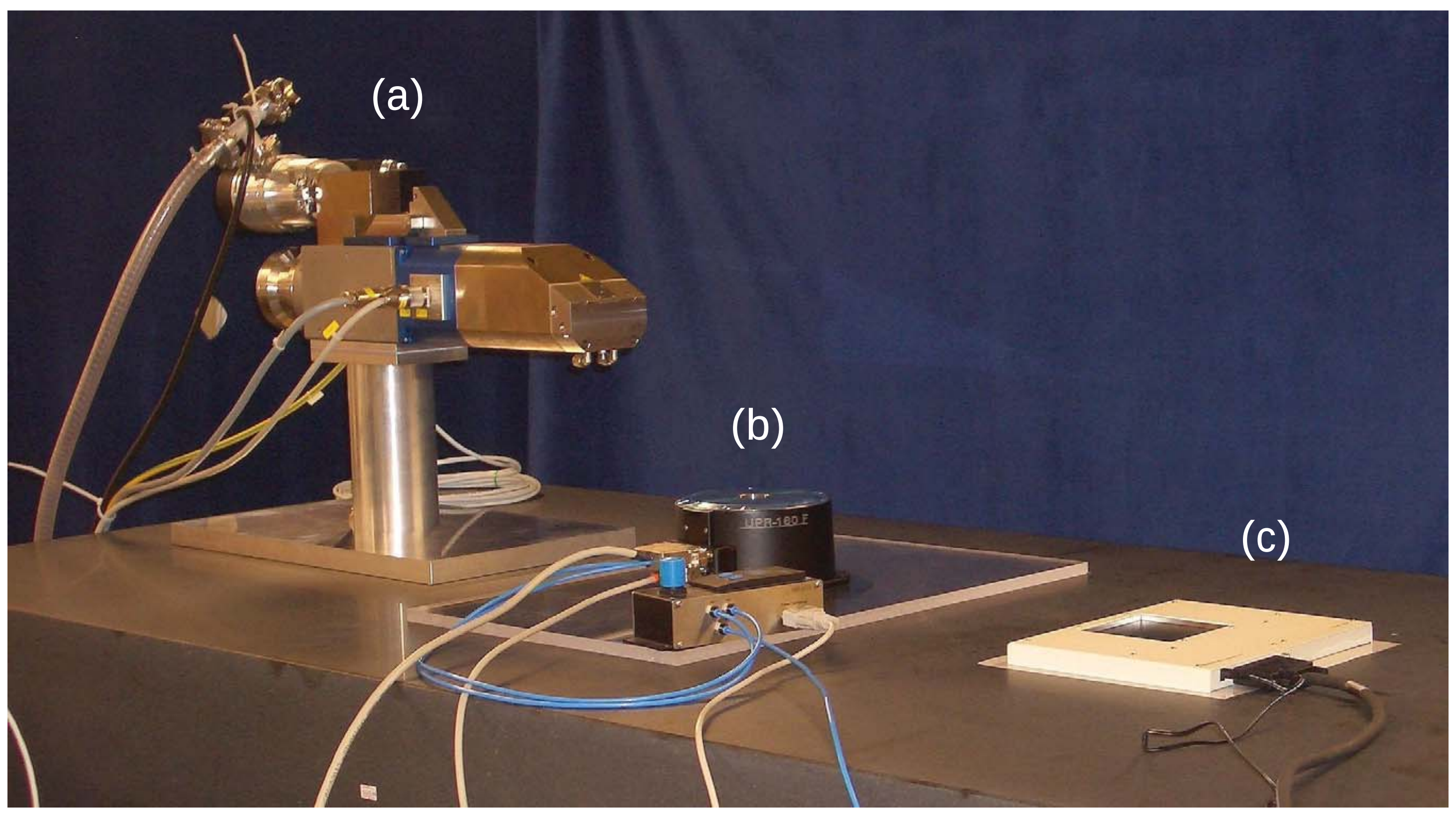

Figure 5. ECOSSE X-Ray CT scanner components: (a) X-ray source (Feinfocus dual head transmission/directional nano/microfocus tube), (b) Air-bearing rotary table (Micos UPR-160F SMC pegasus with taurus motion controller), (c) 4 MP Gadox X-ray camera (Rad-icon Shad-o-Box).
The CT scanner will be used to measure porosity, fracture apertures, saturation and advancing fluid fronts in core samples. As the density of the scanned material is proportional to the recorded radiation intensity, tracer-aided static and dynamic (coreflood) experiments can be monitored.