Project number: A04
Doctoral Researcher: Florian Doster
Title: Die Rolle perkolerender Phasen bei Mehrphasenströmungen in porösen Medien
Supervisors: apl. Prof. Dr. Dr. Rudolf Hilfer, Prof. Dr. Ir. S. Majid Hassanizadeh

Description of doctoral project and research results achieved to date

Understanding macroscopic phenomena of multiphase flow in porous media is of great interest for applications but from a scientific perspective as well. Although it has been a focus of research for more than a century and the dynamics of the fluids on pore-scale are governed by the classical hydrodynamic equations, until now, a theory which predicts comprehensively and physically sound hysteretic phenomena and residual fluid configurations on the laboratory and field scale has not been available. Percolating and nonpercolating fluid parts show fundamentally different hydrodynamic behavior and taking into account these differences on macroscopic scales might be the key to a better model. Hilfer proposes a model (Phys. Rev. E. 73, 016307 (2006)) which treats microscopically percolating fluid regions and nonpercolating regions as distinct phases on a macroscopic scale. In a quasi-stationary limit, the results indicate that the model may solve deficiencies of traditional approaches. Further studies of the proposed model form the objective of this thesis.

The model is investigated by using different strategies including analytical, numerical and modeling techniques. The underlying set of nonlinear, coupled, partial differential equations has been reformulated and approximations have been made to render analytical solutions possible. Closure conditions permitting time-dependent solutions have been proposed. Four initial and boundary value problems have been set and solved analytically and quasi analytically respectively. The problems are generalizations of the Buckley-Leverett problem, the gravity driven redistribution, the McWhorter-Sunada problem and the Philip problem for traditional approaches. Further, four different numerical algorithms have been developed to solve initial and boundary value problems for different mathematical formulations and physical approximations of the model. These algorithms have been used to simulate laboratory experiments. Considered are three different categories of experiments. The first category covers experiments with a closed porous column. In these experiments, gravity as well as capillary and interfacial forces exclusively induce a redistribution of the fluids. The results show that the model predicts hysteresis in the dynamics of the fluids. They illustrate further the similarities and differences to existing models. The results may be checked in the laboratory. The second category covers experiments with a porous column which is streamed by an externally applied flux. The simulations show that residual saturation dynamics are described by the model. The third category covers experiments in which the pressure at the boundaries of the porous column is controlled. Such experiments are usually conducted to measure capillary pressure saturation relations. A comparison of simulations and experimental data shows good agreement.

In this thesis, it has been shown that at least some of the deficiencies of traditional approaches are solved by taking into account the distinct hydrodynamic properties of percolating and nonpercolating fluid parts. Analytical and quasi analytical solutions have been found and numerical methods and algorithms have been developed. Some numerical solutions have been compared to experimental data with good agreement. The other solutions suggest experiments to further validate the model.