Robust numerical algorithms for three-phase flow in porous media

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Motivation: Enhanced oil recovery (EOR) is becoming more and more attractive to researchers from all relevant fields and oil industry, since it is one of the most powerful techniques for meeting the growing energy demand all over the world. Compared with primary and secondary recovery, EOR requires the simulation of more complex processes: water-alternating-gas (WAG) injection, gas (e.g. CO₂) injection, steam flooding, chemical injection and so on. Most of these processes involve three-phase flow of oil, water and gas in reservoirs. Besides EOR, three-phase flow in porous media is also important for geological CO₂ sequestration and the remediation of contaminated unsaturated zones. Considering the world’s energy demand, environmental problems closely related to our daily life and the profit of oil industry, the study of fast and robust numerical algorithms for three-phase flow is extremely necessary and urgent.

State of the art and preliminary work: Robust numerical algorithms for three-phase flow problems will be at the focus of work. Of special interest are large-time-step operator-splitting techniques, and in particular so-called corrected operator splitting (COS) for reservoir flow models in porous media, which are expected to improve the efficiency by allowing even larger time-step sizes. The essential idea of COS is the flux splitting strategy which was first introduced in Espedal and Ewing (1987). Owing to the flexibility of COS, efficient numerical methods associated with the individual types of equations can be properly combined to exploit the overall benefit. Lie and Juanes (2005) have studied the front-tracking method for three-phase flow. For higher-dimensional cases, either dimensional splitting or a streamline approach has to be combined with this method. However, the flux splitting for three-phase flow is non-trivial and a detailed investigation of it is still lacking.

The group of the applicants has already gained experience in investigating and implementing the COS method using the streamline approach for 2/3D two-phase flow models (Cao et al., 2009), and the basic implementation of the fractional flow formulation for three-phase flow including gravity has been done. The knowledge of COS for two-phase flow and the experience with three-phase problems will be a good starting point for further research work.

Goals: The COS method will be applied to the fractional flow formulation of three-phase flow models. Since the streamline approach can follow a natural geometry from the physical point of view and is very efficient considering its memory and computation time, we will employ the front tracking method along streamlines for the COS of 2/3D three-phase flow problems. The main focus of the project will be the development of appropriate flux splitting strategies and their applications to many realistic flow problems.

This project is a further extension of the study on the COS method for two-phase flow with or without gravity carried out by the doctoral researcher Y. Cao (B3). The operator splitting (OS) concept contained in the COS method can be employed in the forthcoming project B13 for the complex two-/three-phase problems on a local scale. On the one hand, the OS can split complex physical processes into simpler sub-problems; on the other hand, the COS method can be applied on this local scale with a fine grid to avoid very small time steps restricted by the CFL condition. This topic can also link with project C12, since the large time scale is always a crucial point for simulating CO₂ storage problems. The COS property for allowing the use of large time steps without losing accuracy may resolve the difficulty in the time discretisation of CO₂ problems. Similar problems and discretisation methods are considered in project N4.
References

