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Stable and efficient time integration at low capillary numbers of a dynamic pore network model for immiscible two-phase flow in porous media

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Numerical instabilities at low capillary numbers is a problem that has been reported for different types of pore network models [2], and first to address the issue was Koplik and Lasseter [4]. As most practical applications are in this regime, such as water flow in fuel cell gas diffusion layers and flow of carbon dioxide some distance away from the injection well in carbon dioxide sequestration, it is important to address such stability issues in a rigorous manner.

The pore network model we consider is of the type first presented by Aker et al. [1]. Since first introduced, it has been improved upon several times. With Aker-type pore network models, the numerical instabilities manifest themselves as non physical oscillations of the fluid interface positions. Some attempts to prevent these oscillations by introducing changes to the model have been made. For invasion of water in a fuel cell gas diffusion layer, Medici and Allen [5] used a scheme that allowed forward flow of water only. The price that is paid when using this approach is that interface movement is severely restricted and some dynamic effects, such as the retraction of the invasion front after a Haines jump, can no longer be resolved. Another limitation is that this scheme can only be used in transient invasion cases and studies of steady-state flow [6] cannot be performed.

As the instabilities are numerical, rigorous attempts deal with them should focus on the numerical methods, rather than introduce changes to the model. Such an approach was pursued by Joekar-Niasar et al. [3], however, for a different type of network model that the one considered here. They used a linearized semi-implicit method to achieve stabilization.

We present numerical procedures that can be used to simulate two-phase flow in porous media at low capillary numbers in a stable manner using the Aker-type pore network models. Thus, we solve the previously observed stability problems without resorting to changes in the model that restrict interface movement or prevent the study of steady-state flow. We will consider three methods, two explicit methods and a new semi-implicit method. The explicit methods are stabilized by a new time step criterion. Further, we present a thorough verification of the all three methods, confirming that they solve the model equations and exhibit correct convergence behavior, and we compare their performance.

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