On the Growth and Relaxation of Viscous Fingering Structures

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The Saffman-Taylor instability, also known as viscous fingering, forms between two fluids of different viscosities in a laminar flow environment. Viscous fingering structures are anisotropic, self-similar, and are part of a family of systems driven by Laplacian growth. This work examines the way self-similarity develops during the growth and relaxation of viscous fingering structures. Radial viscous fingering was generated in a two-dimensional setting. Both the growth and relaxation of the resulting structures were analyzed. The interface between the interacting fluids was extracted. Properties measured include the structures' time-dependent perimeter, fractal dimension, and fingertip curvature. During the growth process, it was observed that the minimal length scale was constant. This enabled a description of the development of the system's fractal dimension using the physical equations describing the system. During the relaxation process, it was observed that the perimeter and fractal dimension exhibited time-dependent decay in accordance with a power law. A coarsening process was identified, consistent with the power law fit. A scaling law between the characteristic size of a finger and the characteristic time of decay was developed. The coarsening process is explained using the scaling law, in agreement with experimental results. As the relaxation process approaches completion, an analytic approximation was performed on the perimeter as a function of time. The characteristic time found agrees with experimental results. This study provided scaling laws that govern the highly nonlinear growth and relaxation of viscous fingering, and are expected to govern the spatial evolution of many other physical and biological systems.

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