A new understanding of patterns in fluid flow

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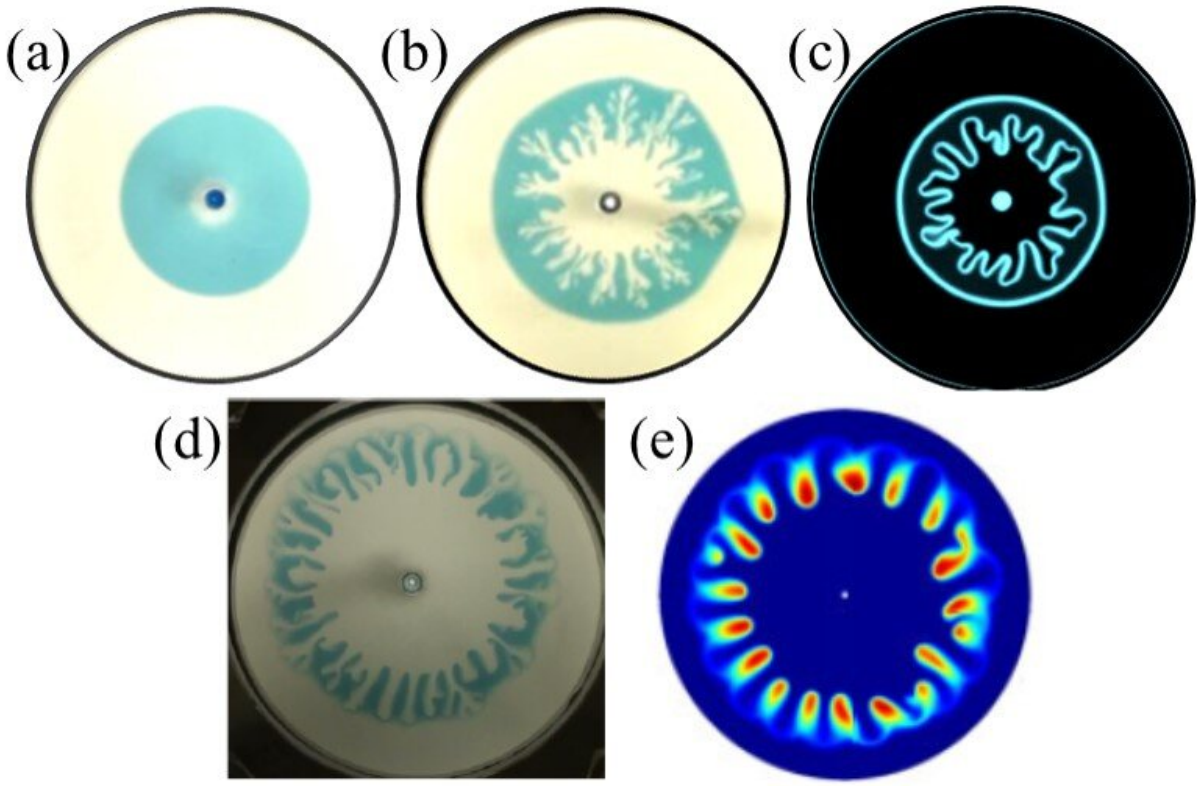

(a) A fluid (blue colored) in finiteness surrounded by less viscous white fluid. (b) VF observed in experiments. (c) VF observed mathematically, here less viscous is shown in black color. (d) A persistent phenomenon observed in experiments. (e) A persistent phenomenon observed mathematically. Credit: Tokyo University of Agriculture and Technology

Scientists have explored, for the first time, the viscous fingering (VF, one of classical interfacial hydrodynamics) of an annular ring, where 'fingers' in a fluid of finite volume grow radially, through a combination of experiment and numerical simulation. They demonstrate that the VF of an annular ring is a persistent phenomenon.

The researchers published their results in the *Journal of Fluid Mechanics* on Apr 6th, 2021.

When a less viscous fluid moves in a more viscous fluid in a porous media, the interface between the two fluids becomes unstable and deforms in a finger shape. Since the 1950s, this VF has been studied as a fluid dynamics issue. VF can be classified according to whether the less viscous fluid displace the more viscous one rectilinearly or radially.

"Classically, VF formed at an interface between two semi-infinite domains of different viscosity have been studied. However, recently, VF formed at either the front or the rear interface of the fluid of finite volume has attracted attention because such VF is relevant to chromatography, spreading of groundwater contamination, and enhanced-oil-recovery. So far, VFs formed in finite volume fluids in linear geometry have been mainly studied only by numerical simulation. However, VFs formed in finite volume fluids in radial geometry have been rarely studied experimentally or numerically." said Dr. Nagatsu, one of the corresponding authors on the paper, Associate Professor in the Department of Chemical Engineering at Tokyo University of Agriculture and Technology (TUAT). "This is because of the complexity of creating finiteness in experiments and difficulties in numerically solving the governing equations."

The research team succeeded in integrated analysis experiments and numerical simulation on VF formed in finite volume fluids in radial geometry (see Figure). The experiments are carried out using a water-

glycerol miscible system in a Hele-Shaw cell which is an experimental apparatus to mimic the porous medium flows. The simulation is done using the two-phase Darcy law (TPDL) module of COMSOL (COMSOL Multiphysics).

"Our team found that the VF of an annular ring is a persistent phenomenon in contrast to the transient nature of VF of a slice (see Figure). Although new fingers cease to appear after some time but due to the radial spreading of the area available for VF, a finite number of fingers always remain at a later time. Furthermore, we clearly showed that VF was observed only if the width of the finite layer exceeds some value," Nagatsu explains.

"Apparently our results shows that the dynamic of VF in annular ring is dramatically different from those classical radial VF and rectilinear VF with one fluid sandwiched between layers of another. VF in annular actually takes place in spreading of groundwater contamination, and enhanced-oil-recovery. Thus, our finding is expected to enable us to make highly accurate prediction of such processes," adds Nagatsu.

More information: Vandita Sharma et al, Viscous fingering of miscible annular ring, *Journal of Fluid Mechanics* (2021). DOI: 10.1017/jfm.2021.124

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