Tears of surfactants in viscous fingering (VF)

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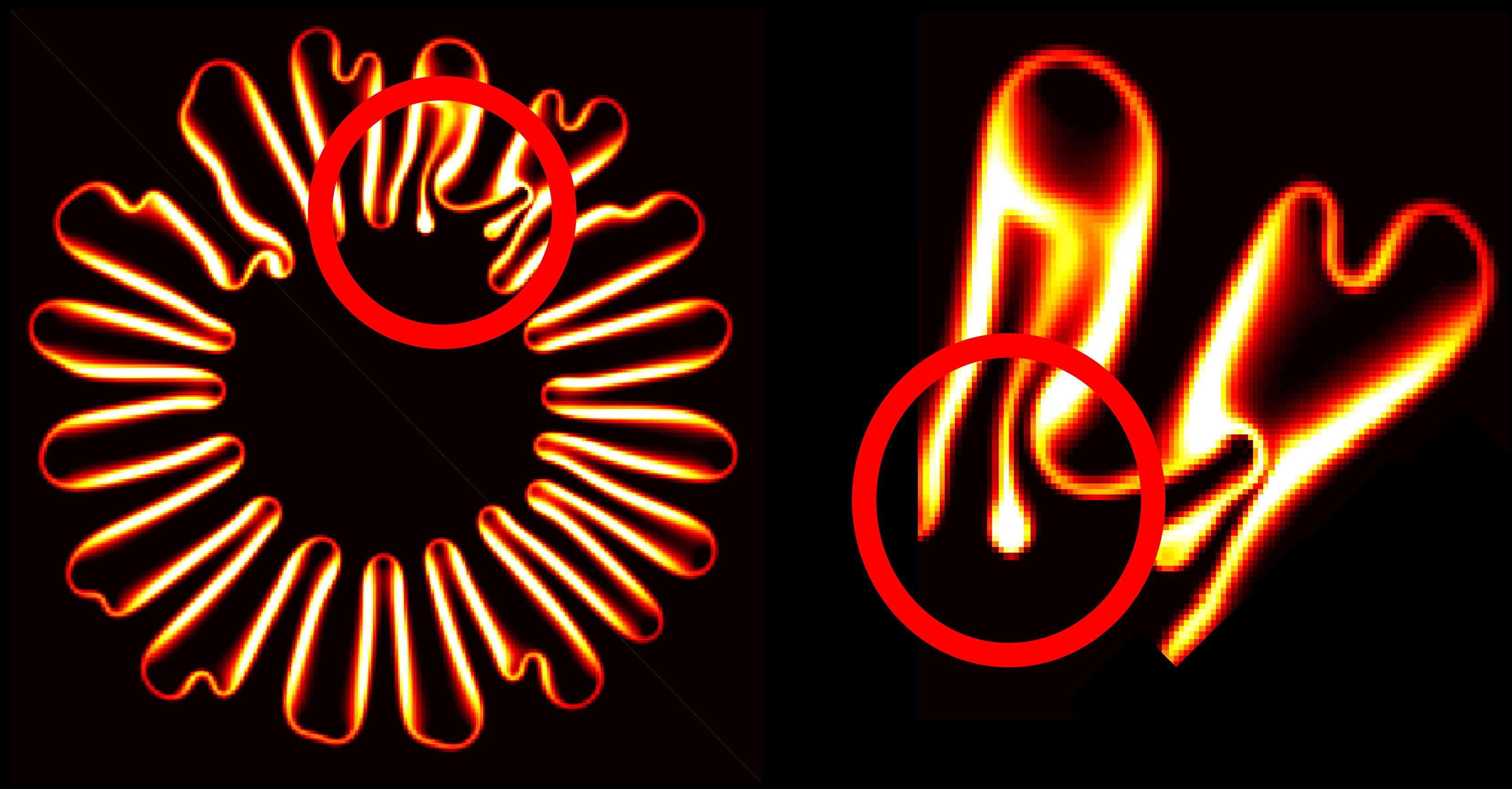
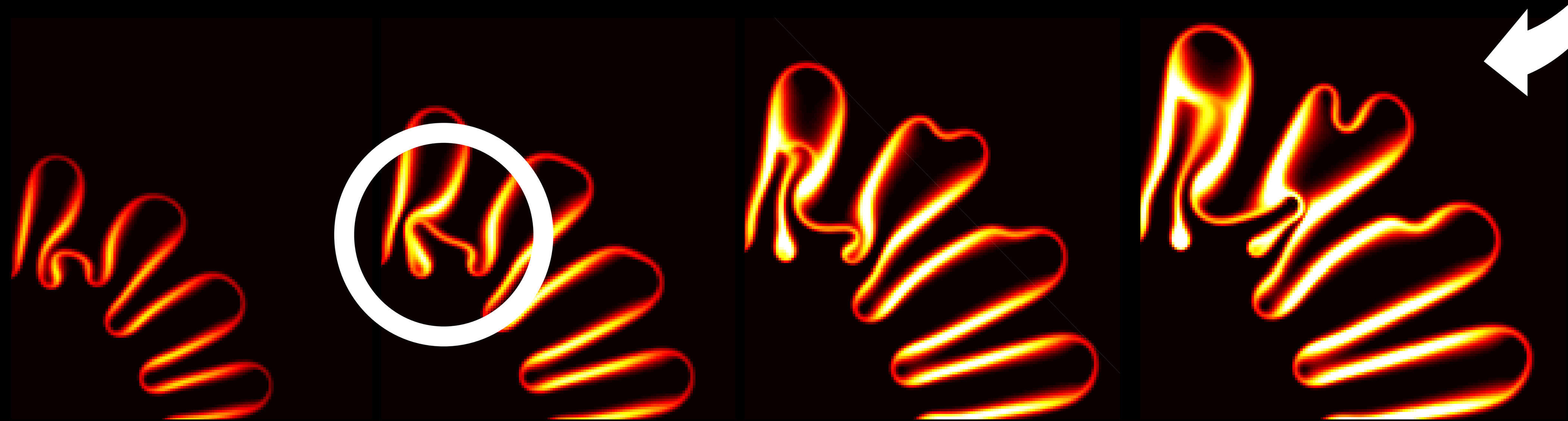


Why tearing, VF?



t = 0.25 **Because VF's merging!** t = 0.55

In a reactive flow, surfactants emerge and disperse on the fluid-fluid interface.
Distribution of surfactant greatly affects the fingering pattern.
The figures show concentration evolution of surfactants in a typical radial VF.
Tear-like formation appears when neighbor fingers start to merge.

Viscous Fingering on an Immiscible Reactive Interface with Variation of Interfacial Tension

Abstract

The effects of chemical reaction, in which surfactants are produced on the interface of two immiscible fluids, on viscous fingerings in a radial Hele-Shaw flow are numerically investigated. In the present study, influences of reaction rate and dispersion of produced surfactants are evaluated systematically. For the case of high Damköhler number side-branching is preferred. Nevertheless, side-branching is suppressed in the cases associated with low Péclet number of surfactant. The patterns obtained by the simulations qualitatively agree with the observations in the experiments [1].

[1] Tsuzuki, Fujimura, and Nagatsu, *Physical Review Fluids* (submitted)

Governing Equations

$$\nabla \cdot \mathbf{u} = 0,$$

$$\nabla p = -\eta \mathbf{u} - \frac{C}{I} \epsilon \nabla \cdot [(\nabla c)(\nabla c)^T]$$

$$\frac{\partial c}{\partial t} + \mathbf{u} \cdot \nabla c = \frac{1}{Pe} \nabla^2 \mu$$

$$\mu = \frac{\partial f_0}{\partial c} - C \nabla^2 c$$

$$\frac{\partial c_s}{\partial t} + \mathbf{u} \cdot \nabla c_s = \frac{1}{Pe_s} \nabla^2 c_s + Da\,(1-c)c$$

$$\epsilon(c_s) = 1 - \Gamma \ln(1 + \kappa c_s) \quad if \;\; \epsilon \geq \epsilon_s$$

$$\epsilon = \epsilon_s \quad if \; 1 - \Gamma \ln(1 + \kappa c_s) \leq \epsilon_s$$

$\mathbf{u}$: velocity vector
p : pressure
η : viscosity
ϵ : coefficient of capillary
c : phase-field variable
μ : chemical potential
f_0 : Helmholtz free energy
c_s : concentration of surfactants
Γ : adsorption constant
κ : adsorption constant
C : Cahn number
I : injection strength
Pe : Péclet number
Pe_s : Péclet number of surfactant
Da : Damköhler number

(a) I = 1, Da = 200, Pe_s = 1200 (b) I = 2, Da = 100, Pe_s = 2400 (c) I = 4, Da = 50, Pe_s = 4800 (d) I = 8, Da = 25, Pe_s = 9600

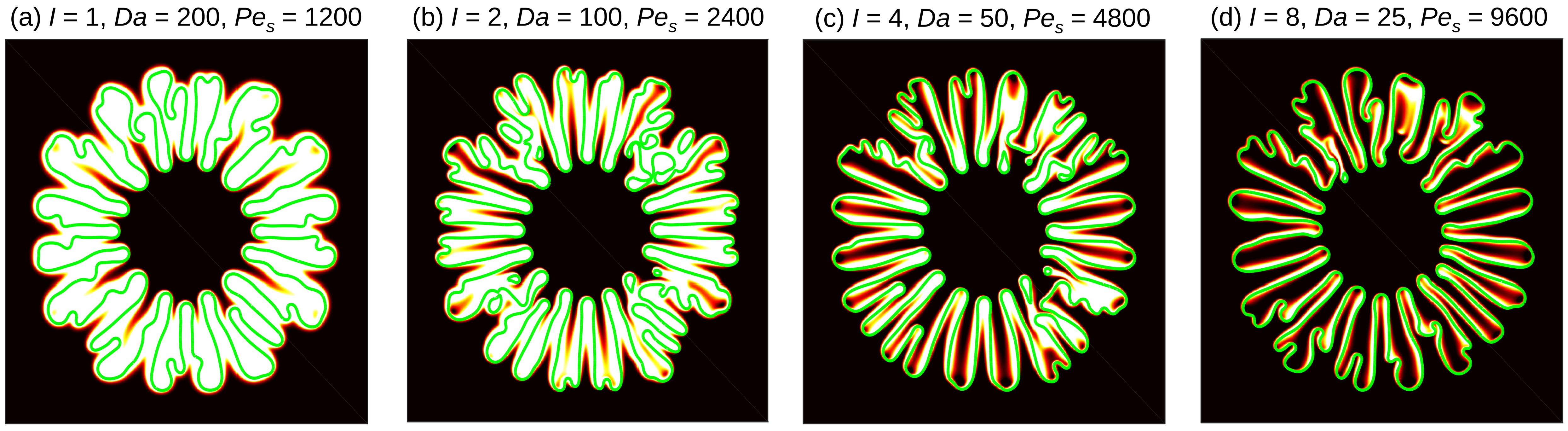


Figure The green curve represents the interface of the immiscible fluids. Brightness of background indicates the concentration of surfactant. $Da*I$ = 200, Pe_s/I = 1200.