Precipitation dendrites in non-laminar pipe flows

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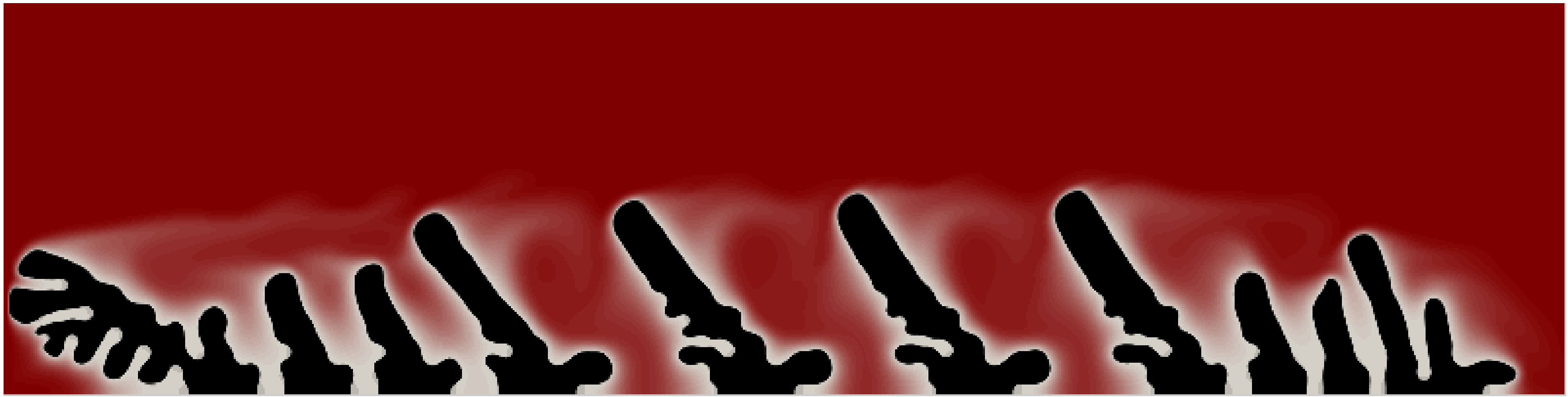
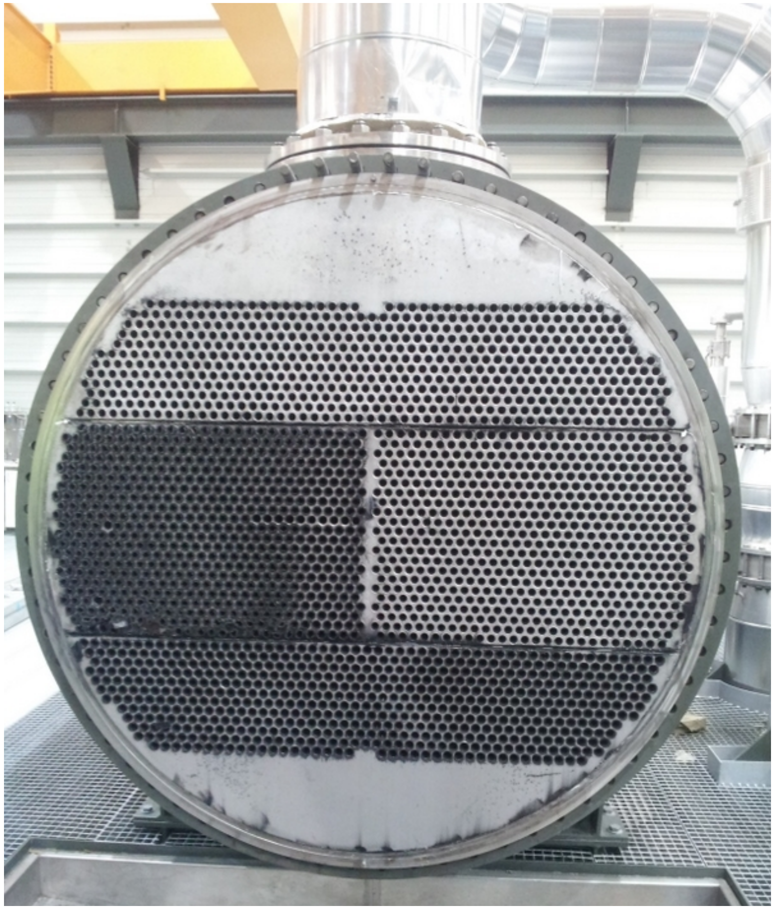
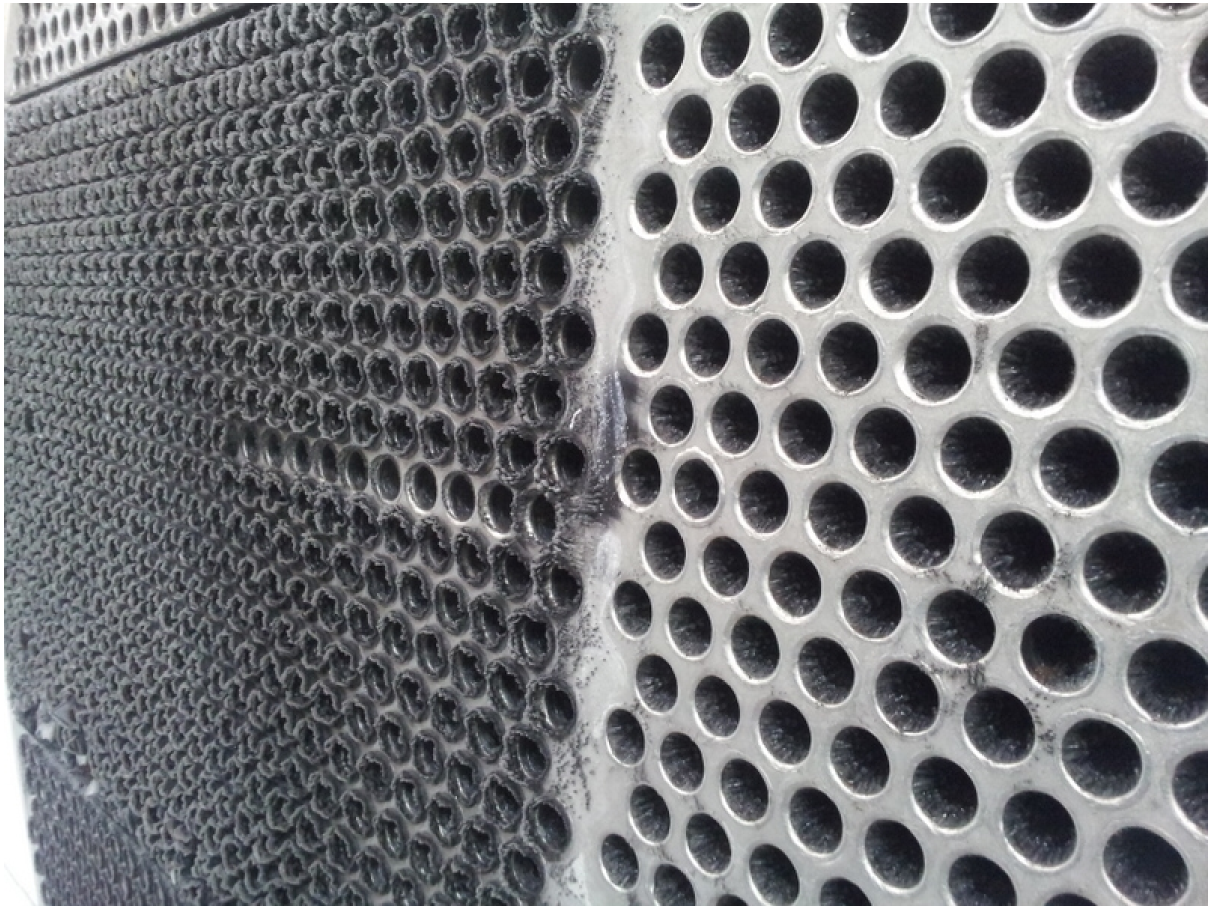


Mineral scaling in pipelines

- Mineral scaling (precipitation) in pipelines causes clogging reducing flow efficiency
- Phenomenon common in nature as well as in man-made systems (pipelines, boilers, etc)
- Costly and time consuming process to remove
- Can we understand the growth through simulations

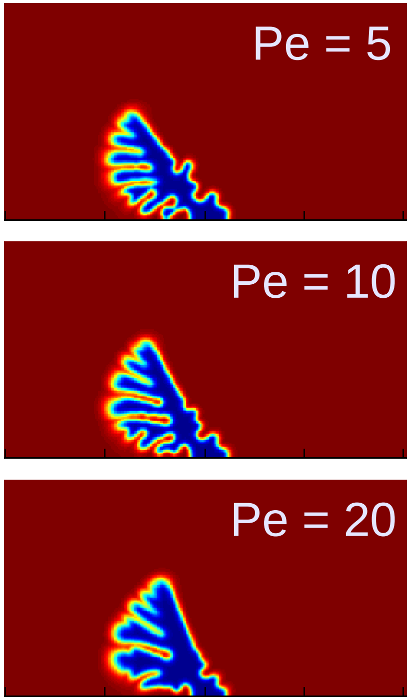
Heat Exchanges from Geothermal power plant, Iceland



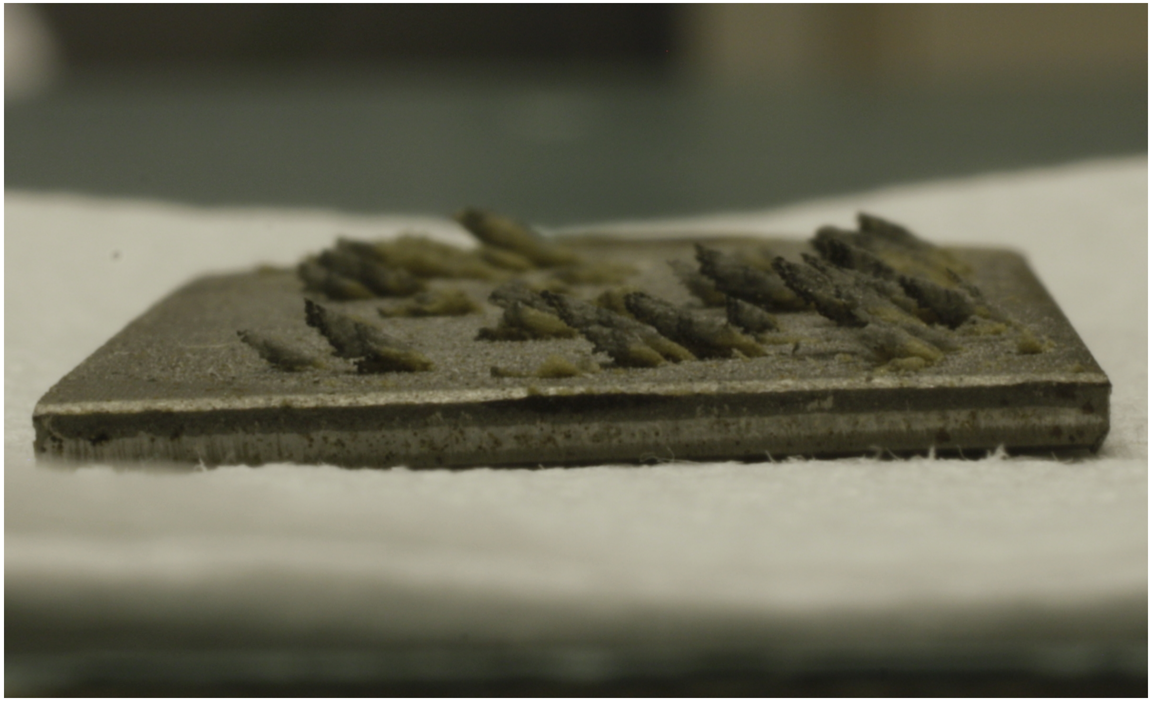


- Precipitation buildup over time reduces effectiveness of heat exchange
- Flow rate reduced from lower cross section

Comparison of simulated and true life precipitation in pipes



Simulated precipitation structures



Samples of precipitation from hydro-thermal pipelines in Iceland

Growth tilts towards flow, Branched growth in upstream direction, Smooth surface downstream

Precipitation dendrites in channel flow – Christopher Hawkins, Øyvind Hammer Luiza Angheluta, Bjørn Jamtveit – EPL 102 54001 (2013)

Model to simulate reactive flow

Fluid flow –
Navier-Stokes equations solved using Lattice Boltzmann

$$\rho \left(\frac{\partial \mathbf{u}}{\partial t} + \mathbf{u} \cdot \nabla \mathbf{u} \right) = -\nabla p + \mu \nabla^2 \mathbf{u} + f$$

Precipitation –
Interface tracking and first order reactions simulated using Phase-field model

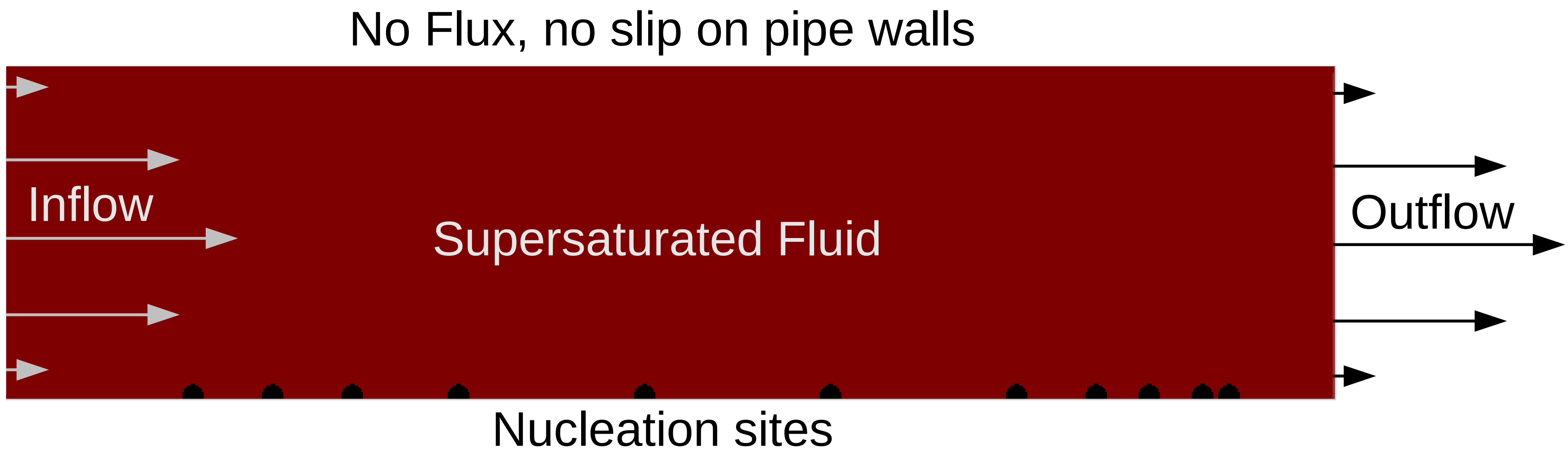
At the interface

$$\frac{\partial c}{\partial t} = -Kc$$

In the bulk

$$\frac{\partial c}{\partial t} = D\nabla^2 c \; - \underline{\mathbf{u} \cdot \nabla c}$$

Setup for pipe flow with precipitation



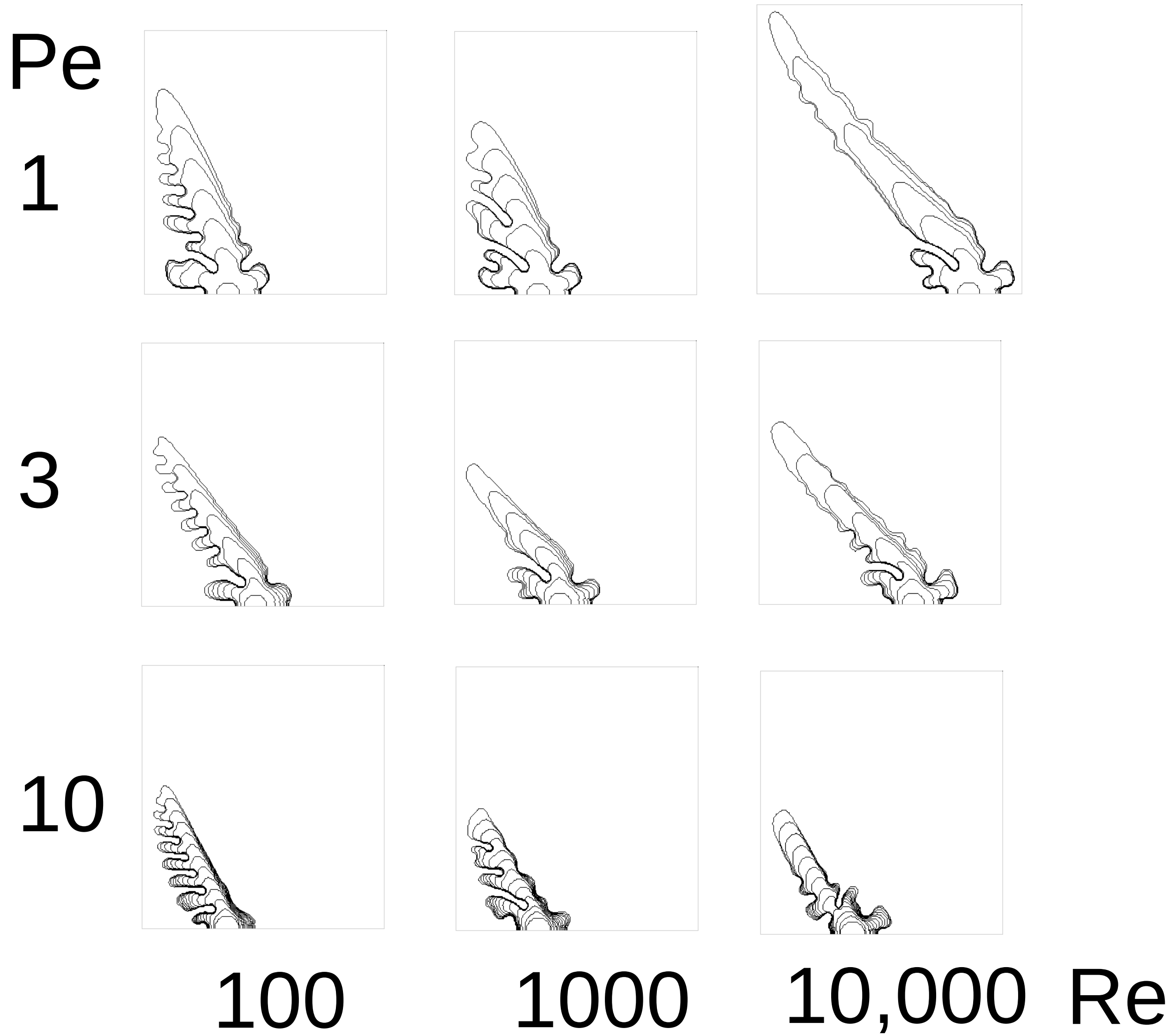
- Conditions intended to match real reactive flow in pipelines
- Randomly spaced nucleation sites negate any resonance effects
- Can we understand the mechanisms which affect real systems by using simulations?

Evolution of concentration field and precipitating solids in pipe flow

Pe = 10, Re = 1000
Gradient – Concentration field
Black – Precipitated Solid

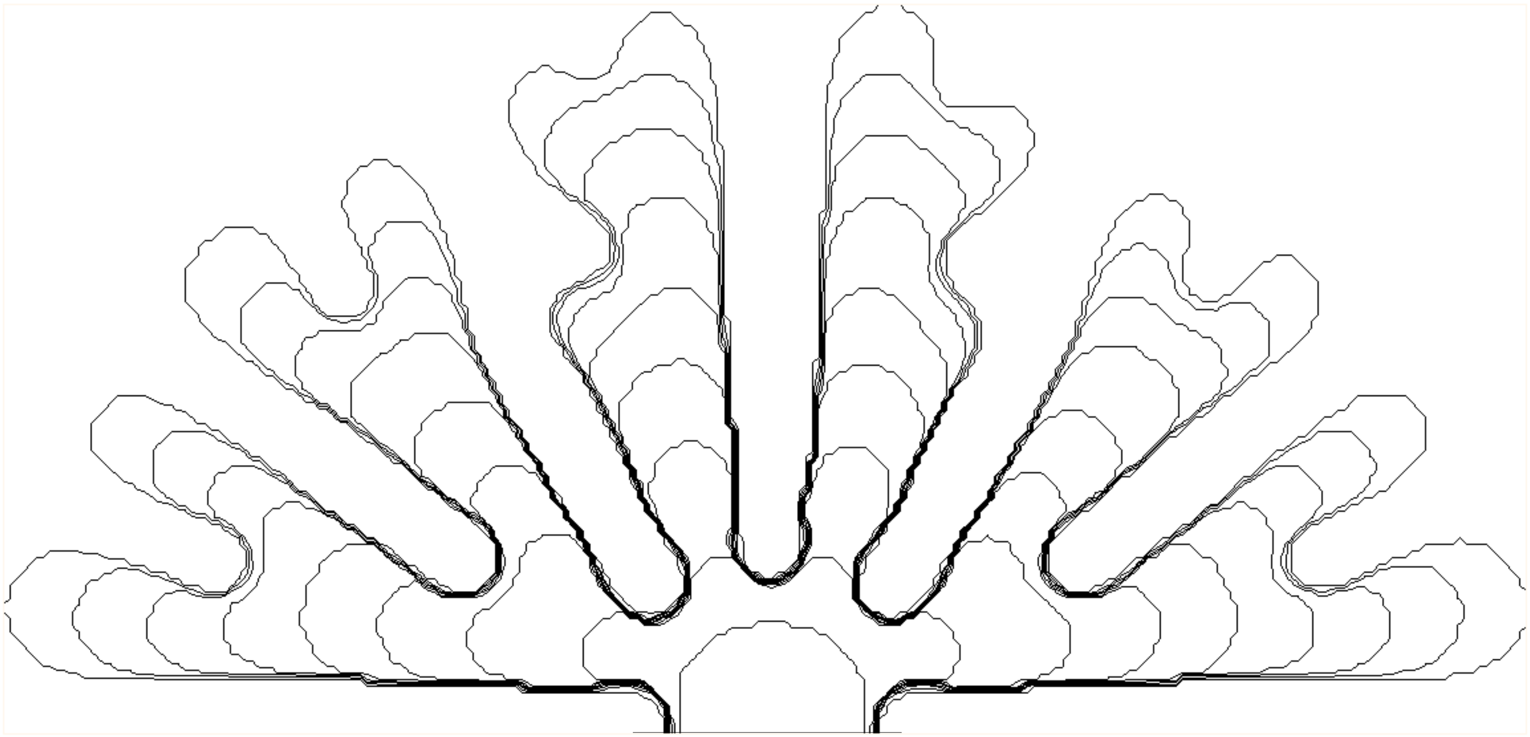
Competition of advection, diffusion and turbulent mixing determines observed morphology

Simulated dendrite phase diagram



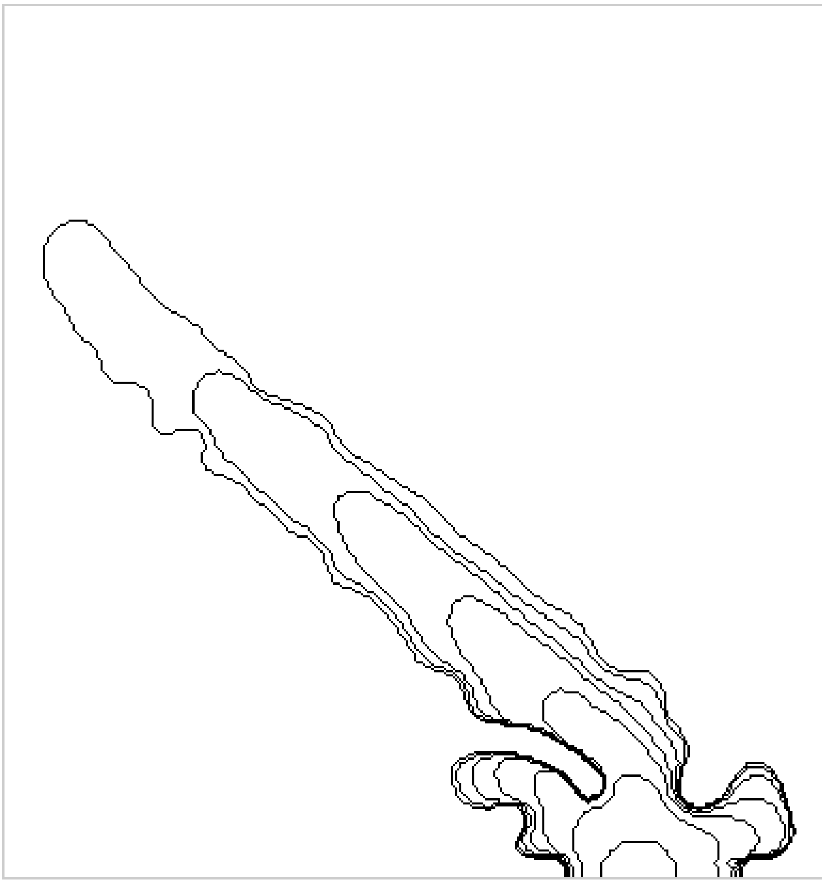
Difference in morphology for various changes in physical parameters (orientation, shape, growth rate)

Diffusion limited growth

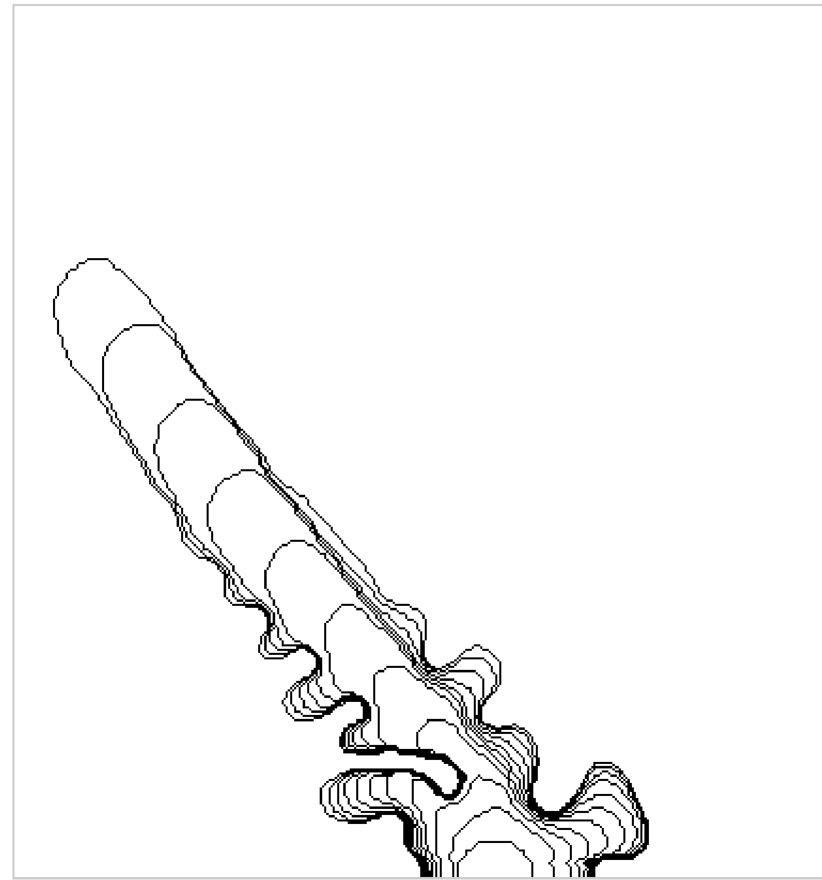


- Symmetric growth
- Fingering (Dendrites) from competition of dendrites experiencing diffusion limited growth

Effect of Advection upon morphology



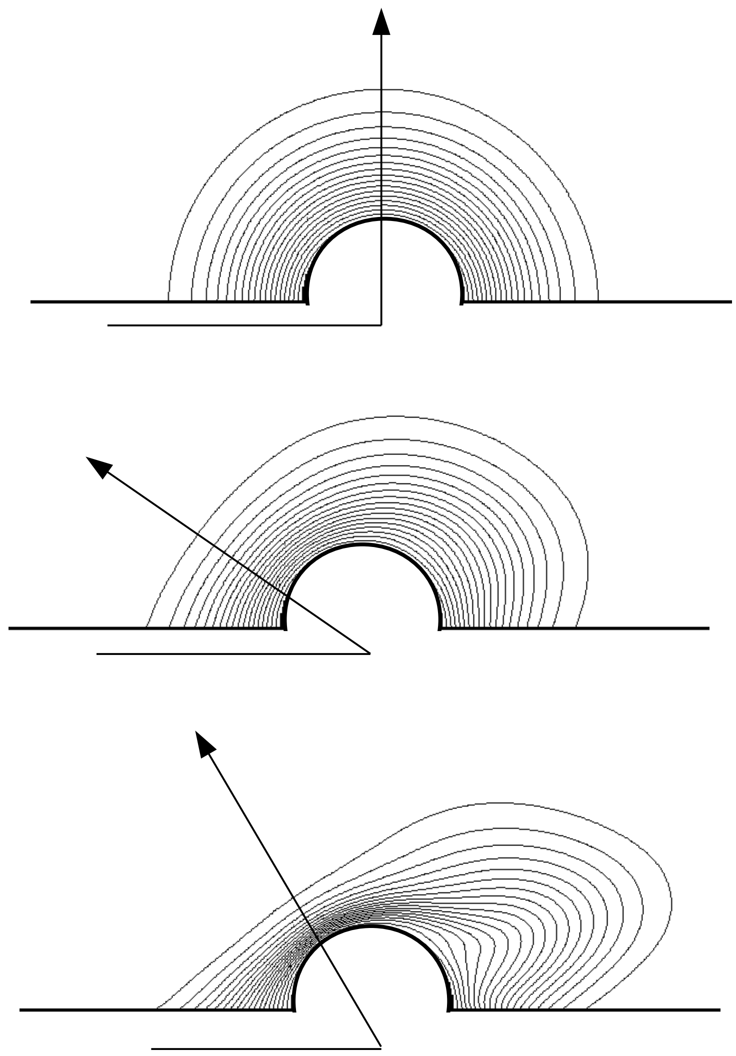
Pe = 2



Pe = 5

- Advection causes dendrite to grow towards flow
- Max angle where Advection and diffusion rates are equal (Pe 1)
- Return to symmetric growth as Pe -> Infinity

Effect of Advection upon concentration



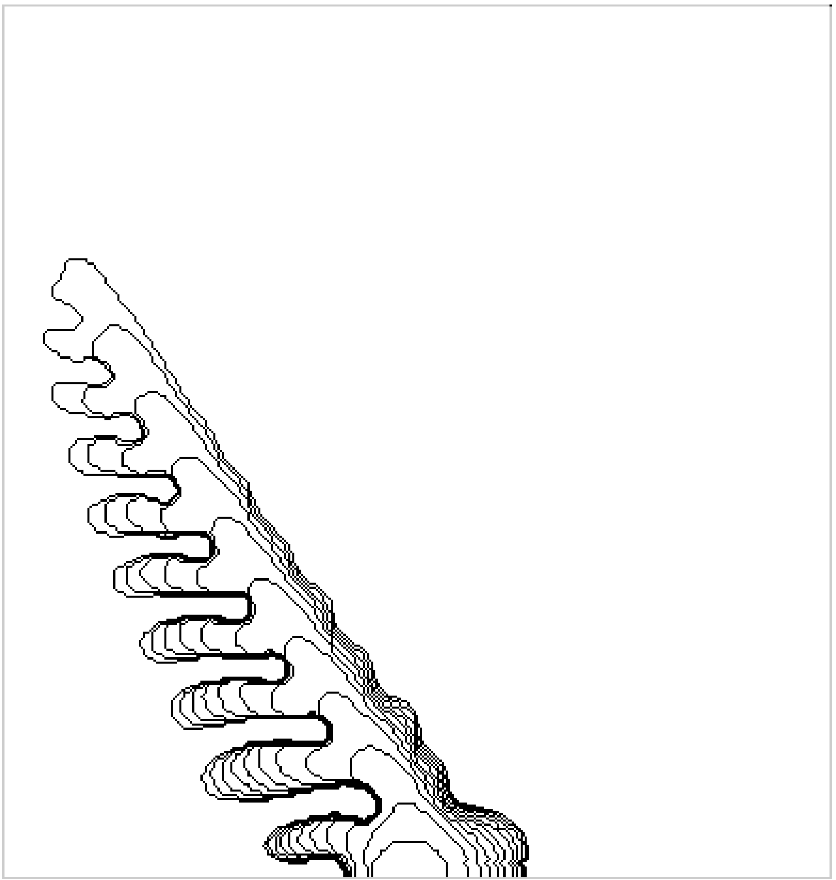
Pe << 1

Pe = 1-3
(Max angle)

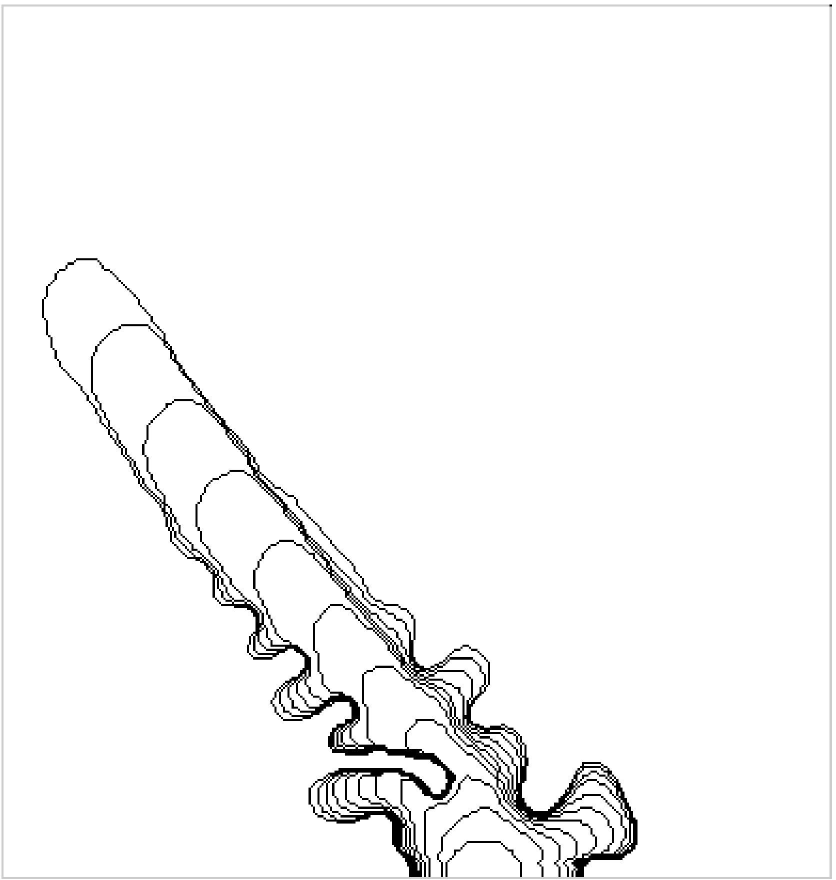
Pe > 5

Advection - Shifts point of steepest concentration gradient from max angle back towards 90 degrees

Effect of Turbulent Mixing upon morphology



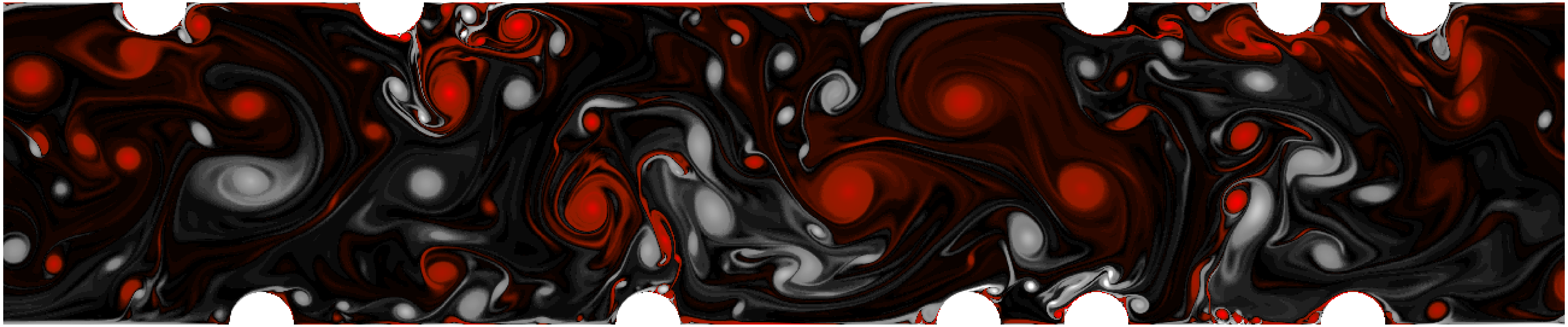
Re 100

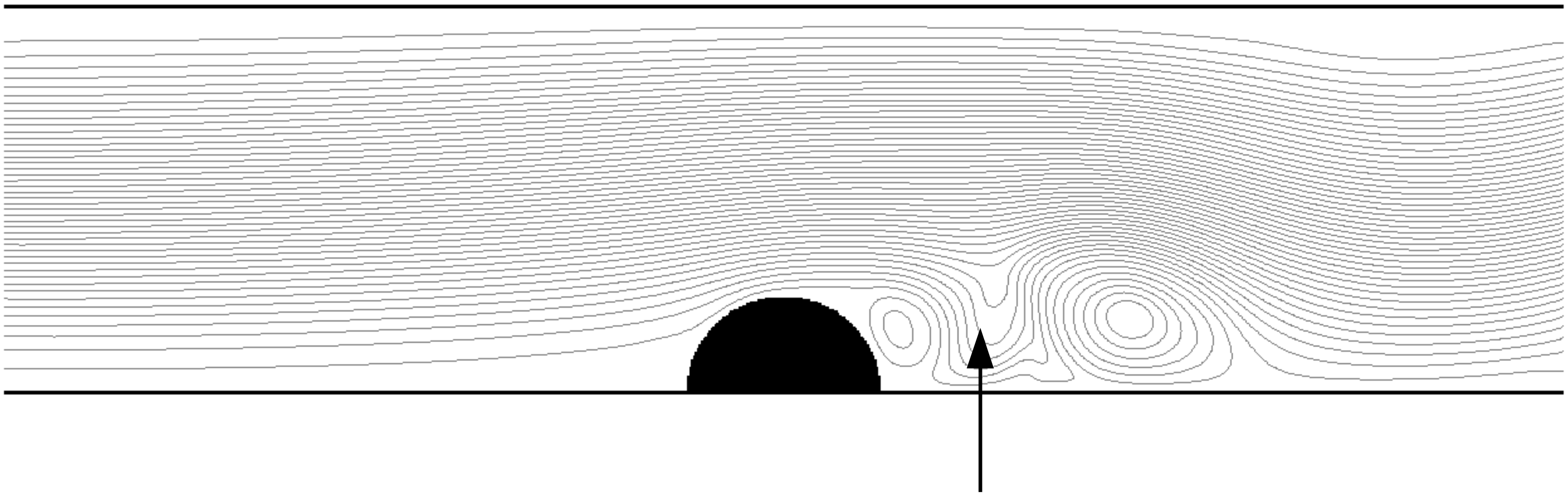


Re 10,000

Turbulent mixing – Increases effective diffusion rate in all turbulent areas

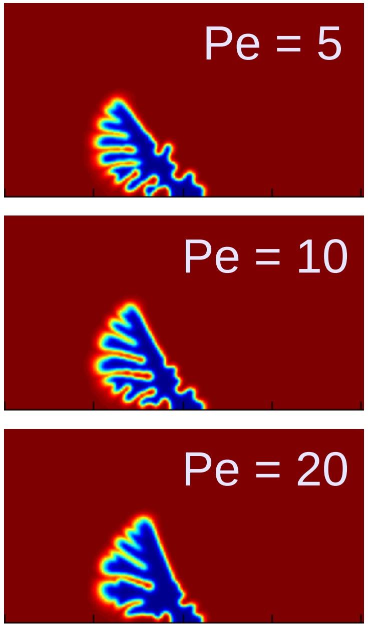
Areas of turbulent mixing

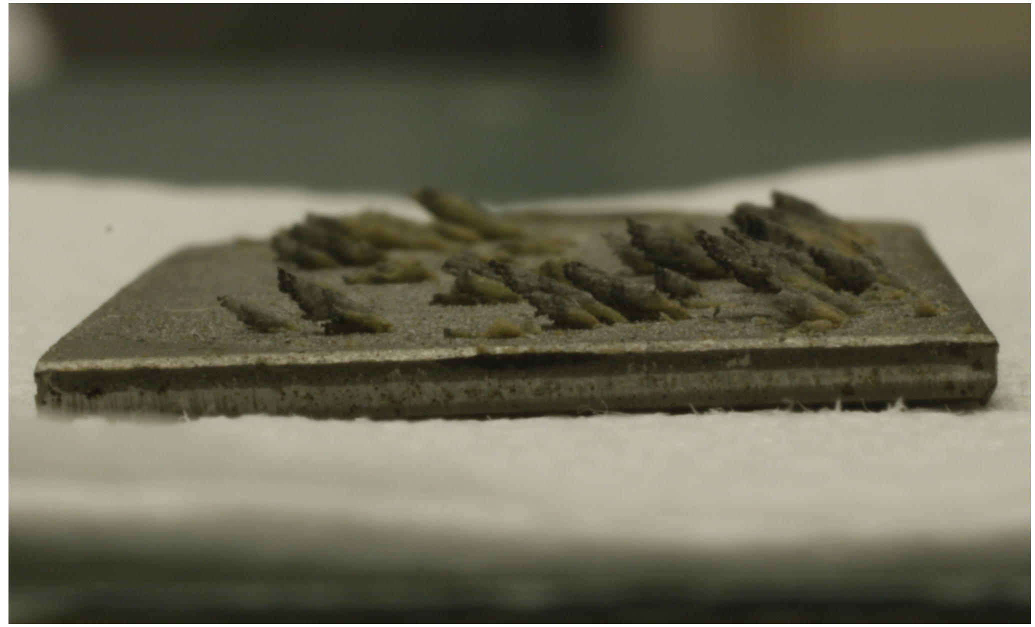




- Turbulent mixing generated downstream of solid structures
- Enhanced diffusion in this area = Faster dendrite like growth

Conclusion - precipitation in pipe flow





Morphology of precipitating structures controlled by: Diffusion, Advection & Turbulent Mixing

- Diffusion – Causes symmetric, dendritic (finger like) growth
- Advection – Accelerates growth in direction of flow
- Turbulent Mixing – Enhances diffusion downstream solid structure

Hydrodynamic shadowing effect during precipitation of dendrites in channel flow – Christopher Hawkins Luiza Angheluta, Bjørn Jamtveit – PhysRevE.89.022402 (2014)