Wormholing in anisotropic media: Pore orientation effect on large-scale patterns

R. Roded¹, P. Szymczak²

¹Hydrology and Water Resources, The Hebrew University, Jerusalem, Israel
²Institute of Theoretical Physics, Faculty of Physics, University of Warsaw, Warsaw, Poland
The network model

- Reactive flow is studied using analog model of network of cylindrical channels (Hoefner and Fogler, 1988; Roded et al., 2018)

- Fluid fluxes resolved from mass conservation of fluid

- Solute concentrations and solid dissolved from solute conservation equations

- Solute transport by advection and diffusion, and 1st-order reaction
Wormhole competition

- Positive feedback between reaction and transport

- Longer wormholes increase their flow on the expanse of shorter ones and screens them off

\[ N_L \sim L_{\alpha} \]

- Hierarchical scale-invariant distribution of wormhole lengths (Szymczak & Ladd, 2006)

\[ N(L_w) \sim L_w^{-\alpha} \quad \text{where} \quad \alpha \approx 1 \]

- Shared dynamics and patterns to other unstable growth processes, e.g. viscous fingering
Wormholing in anisotropic media

- Anisotropy alters wormholing pattern and permeability evolution.
- For large $S$, enhanced interaction via the pressure field results in stronger competition.

$$S = \frac{a_y}{a_x}$$
Wormhole distribution

• For larger $S$ the power-law distribution with $\alpha \approx 1$ is kept, however not for $S < 1$

• Consistent with recent experiments of viscous fingering in a microfluidic networks (Budek et al., 2015)

$$A_c = L_y / L_x$$

• Accordingly, spacing and aspect ratio scales linearly with $S$, $A_c \sim S$

• Here, while $A_c$ increases with $S$ it does not follow a linear trend but shows a fit to power-law, $A_c \sim S^\beta$
Wormhole shape

- Smaller $S$ associated with larger wormhole aspect ratio, $A_w = L_w/b$

- Smaller $S$ and spacing lead to reactivity decay and conical wormholes

- For large $S$ wormhole widen downstream as flow governs

- $A_w$ tends to level-off

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Low $S$ conditions

- Competing side-branches

- We use a simple system with a central preexisting channel

- For $S=0.1$ pressure perturbation induced by the channel, decays sharply in the transverse direction

- Promote sideways directed flow and development of branches
Conclusions

- Anisotropy alter wormholing pattern and permeability evolution, including:
  
  i. Wormhole competition and the characteristic separation
  
  ii. Wormhole shape and tendency to develop side-branches

- Findings are comparable with results of similar process—viscous fingering

- However, while in viscous fingering for $S \geq 1$ spacing scales linearly with $S$, the increase is non-linear for wormholing

- This could be attributed to the effect of anisotropy on wormhole shape and advancement velocity, and remains the subject for future investigation
References


