Chemical Engineering Science 64 (2009) 3029 – 3030

Contents lists available at ScienceDirect

Chemical Engineering Science

journal homepage: www.elsevier.com/locate/ces

Letter to the Editor

Comment on: "From pore scale to wellbore scale: Impact of geometry on wormhole growth in carbonate acidization by C.E. Cohen et al. [Chemical Engineering Science 63, 3088–3099, 2008]"

P. Szymczak[a,*], A.J.C. Ladd[b]

[a] Institute of Theoretical Physics, Warsaw University, Hoża 69, 00-618, Warsaw, Poland
[b] Chemical Engineering Department, University of Florida, Gainesville, FL 32611-6005, USA

During the dissolution of porous rock, positive feedback between fluid transport and mineral dissolution leads to the spontaneous formation of pronounced wormhole-like channels. In a recent paper, Cohen et al. (2008) analyzed wormhole growth in a dissolving porous rock, using a Darcy-scale numerical model developed by Golfier et al. (2002). In particular, they analyzed the competition between wormholes, which hinders the growth of shorter channels and leads to the emergence of a hierarchical structure, with many short wormholes, and only a few long ones. By analyzing the distribution of wormhole lengths (reproduced in Fig. 1) they found evidence for the existence of a characteristic length $d \approx 5\,\mathrm{cm}$, at which a change in slope occurs. They concluded that the wormhole competition process is not completely scale invariant. The length scale d was interpreted as marking a transition to a regime where the interplay of diffusion and convection of reactant within a wormhole plays a decisive role in its growth.

The conclusions of Cohen et al. (2008) were based on a piecewise linear fit of the data (Fig. 1), plotting the number of wormholes, $N(L)$, longer than a given length L. Here, we would like to suggest another way of interpreting the above data. In a recent paper (Szymczak and Ladd, 2006) we analyzed a closely related problem of channel growth and competition in a dissolving rock fracture, using both a pore-scale numerical model (Szymczak and Ladd, 2004) and a simpler, resistor network model. Both models gave rise to a scale-invariant distribution of wormhole lengths of the form

$$N(L) = AL^{-\alpha}. \tag{1}$$

The above distribution was observed in the whole range of wormhole lengths, with no indication of a characteristic lengthscale. In fact, such scale-invariant distributions are a characteristic feature of a large number of competitive growth processes (Krug, 1997); for example, viscous fingering (Roy et al., 1999), dendritic side-branch growth in crystallization (Couder et al., 2005) and crack propagation in brittle solids (Huang et al., 1997).

Interestingly, if the data of Cohen et al. (2008) is plotted on a log–log scale, a clear linear trend is observed over the whole range of wormhole lengths, as seen in Fig. 2. The fit to Eq. (1) gives a slope that corresponds to a power $\alpha \approx 0.91$. This is somewhat different

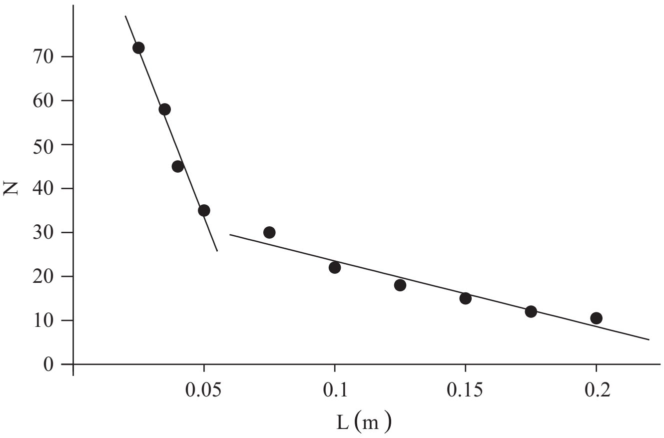

Fig. 1. The number of wormholes $N(L)$ longer than L in a two-dimensional porous medium for an injection velocity of $10^{-3}\,\mathrm{m\,s^{-1}}$. The data is taken from Figs. 2 and 3 of Cohen et al. (2008).

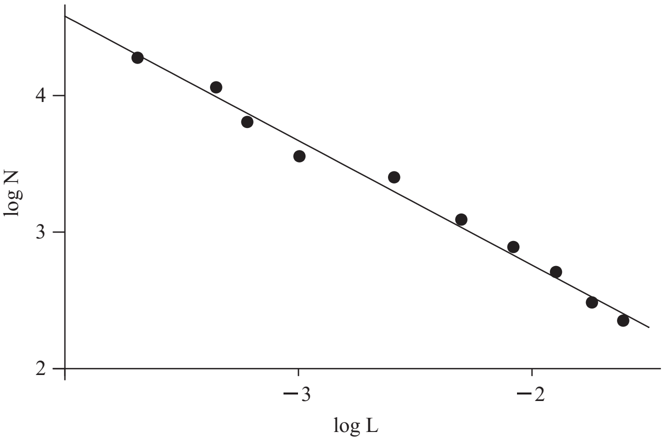

Fig. 2. The same data as in Fig. 1 plotted on a log–log scale with a fit to a scaling law $N(L) \sim L^{-\alpha}$.

---

[*] Corresponding author.
E-mail address: Piotr.Szymczak@fuw.edu.pl (P. Szymczak).

doi:10.1016/j.ces.2009.02.048

Please cite this article as: Szymczak, P., Ladd, A.J.C., Comment on: "From pore scale to wellbore scale: Impact of geometry on wormhole growth in carbonate acidization by C.E. Cohen et al. [Chemical Engineering Science 63, 3088–3099, 2008]". Chemical Engineering Science (2009), doi: 10.1016/j.ces.2009.02.048

from the value reported in Szymczak and Ladd (2006) for wormhole growth in fracture dissolution ($\alpha \approx 1.2$), which may reflect physical differences between the two processes as well as the different boundary conditions used in the simulations (constant pressure drop vs. constant flow rate).

If the data is interpreted in the manner we suggest, no characteristic length scale emerges and the scaling is fully self-affine. We believe that this interpretation of the wormhole length distribution provides an interesting and simpler alternative to the linear fits used by Cohen et al. (2008).

Acknowledgements

This work was supported by the Polish Ministry of Science and Higher Education (Grant no. N202023 32/0702), and by the US Department of Energy, Chemical Sciences, Geosciences and Biosciences Division, Office of Basic Energy Sciences (DE-FG02-98ER14853).

References

Cohen, C.E., Ding, D., Quintard, M., Bazin, B., 2008. From pore scale to wellbore scale: impact of geometry on wormhole growth in carbonate acidization. Chem. Eng. Sci. 63, 3088–3099.

Couder, Y., Maurer, J., González-Cinca, R., Hernández-Machado, A., 2005. Side-branch growth in two-dimensional dendrites. I. Experiments. Phys. Rev. E 71 (3), 31602.

Golfier, F., Zarcone, C., Bazin, B., Lenormand, R., Lasseux, D., Quintard, M., 2002. On the ability of a Darcy-scale model to capture wormhole formation during the dissolution of a porous medium. J. Fluid Mech. 457, 41.

Huang, Y., Ouillon, G., Saleur, H., Sornette, D., 1997. Spontaneous generation of discrete scale invariance in growth models. Phys. Rev. E 55, 6433.

Krug, J., 1997. Origin of scale invariance in growth processes. Adv. Phys. 46, 139–282.

Roy, A., Roy, S., Bhattacharyya, A.J., Banerjee, S., Tarafdar, S., 1999. Discrete scale invariance in viscous fingering patterns. Eur. Phys. J. B 12, 1–3.

Szymczak, P., Ladd, A.J.C., 2004. Microscopic simulations of fracture dissolution. Geophys. Res. Lett. 31, L23606.

Szymczak, P., Ladd, A.J.C., 2006. A network model of channel competition in fracture dissolution. Geophys. Res. Lett. 33, L05401.

Please cite this article as: Szymczak, P., Ladd, A.J.C., Comment on: “From pore scale to wellbore scale: Impact of geometry on wormhole growth in carbonate acidization by C.E. Cohen et al. [Chemical Engineering Science 63, 3088–3099, 2008]”. Chemical Engineering Science (2009), doi: 10.1016/j.ces.2009.02.048