Effects of Membrane Morphology on Flow and Fouling: Modeling of Connected Branched Membrane Filters

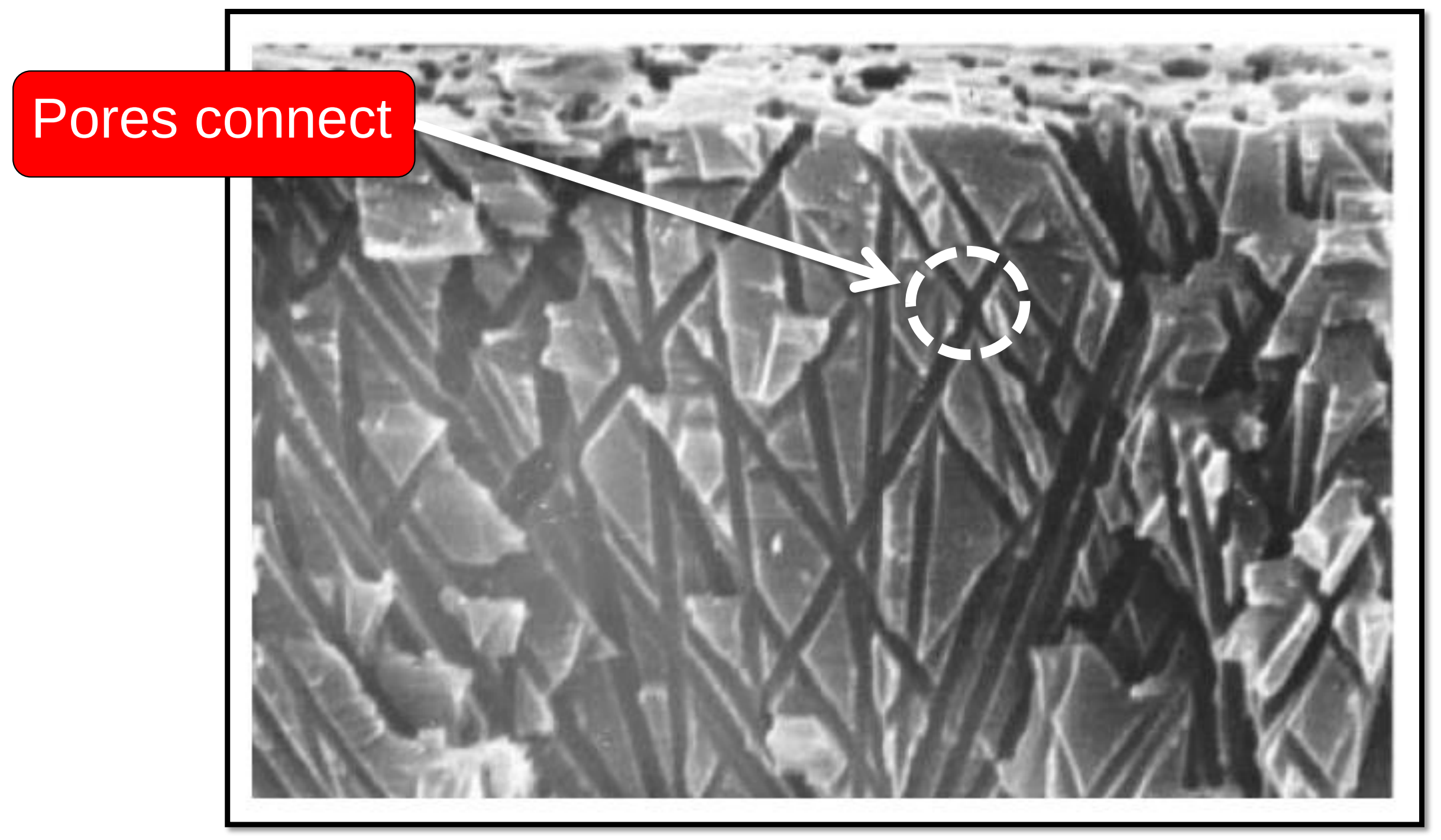
Dylan Renaud[1,2], Binan Gu[2,3], Pejman Sanaei[3,4], Linda Cummings[2,3], Lou Kondic[2,3]

[1]Department of Mathematical Sciences, New Jersey Institute of Technology, Newark, New Jersey, U.S.A.
[2]Department of Physics, New Jersey Institute of Technology, Newark, New Jersey, U.S.A.
[3]Center for Applied Mathematics and Statistics, New Jersey Institute of Technology, Newark, New Jersey, U.S.A
[4]Courant Institute of Mathematical Sciences, New York University, New York City, New York, U.S.A

Abstract

In this work, we study the influence of a membrane's internal structure on its flow and fouling behaviour. This project stems from previous studies by Sanaei et al. on non-connected branched-pore membrane filters [1-3]. We now extend components of these works to investigate the influence of intra-layer connections in such filters. For symmetric membranes, our results demonstrate that the relative performance of connected and non-connected membranes is strongly dependent on membrane morphology parameters (e.g. top layer porosity). Additionally, we show that the filtration efficiency can decrease with time depending on the presence of pore connections. This is a particularly important phenomenon for manufacturers producing membranes with threshold filtration efficiencies.

Introduction



Primary motive: How important are intra-layer connections in membrane filters? When simulating the performance of such filters, do connected membranes differ strongly from their non-connected counterparts? Photograph is a real membrane with a connected structure (Apel 2001).

Modeling

1) We consider Darcy flow through our connected membranes. First, pores in a given layer are treated as identical cylindrical tubes for which the Hagen-Pousille model is applied. Thus, for a single pore in the i-th layer we have

$$Q_i = -\frac{1}{\mu R_i}\frac{P_i - P_{i-1}}{D_i} \quad , \quad R_i = \frac{8}{\pi A_i^4} \quad : \quad 1 \le i \le m$$

2) By continuity of fluid flow, the global superficial Darcy velocity is related to the volumetric flow rate in a given layer, giving us

$$(2W^2)U = \frac{P_0}{\mu R}$$

where *R* is

$$R = \sum_{i=1}^{m} \frac{R_i D_i}{i+1}$$

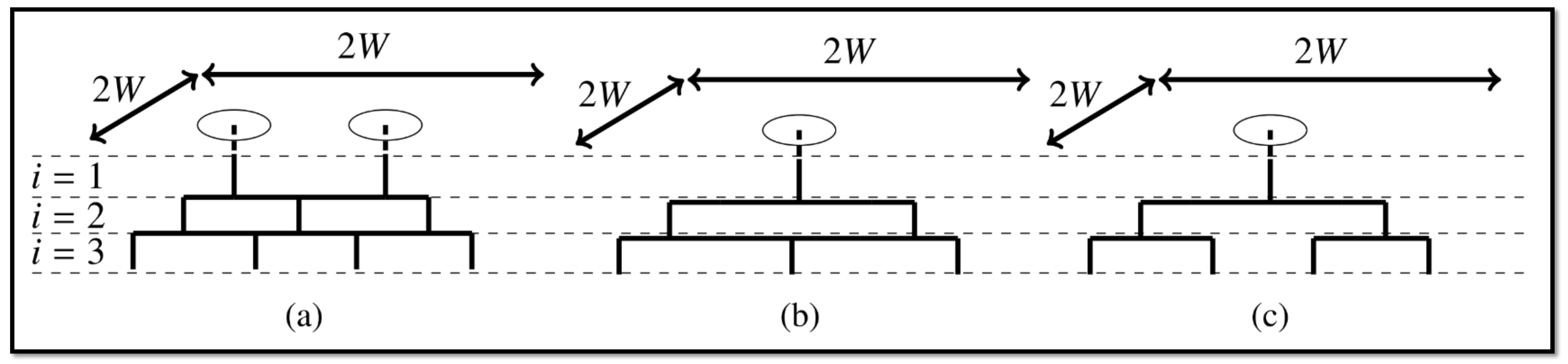
Modeling, cont.

3) Fouling by way of adsorption is incorporated by first considering advection of particles along pore depth. Concentration of particles along pore wall is obtained through advection-diffusion equation. Adsorption is then modeled as pore radius shrinkage. Shrinkage is directly proportional to local particle concentration and pore-wall attraction coefficient (Λ) [2,3]. All equations are later non-dimensionalized (not shown).

$$\bar{U}_{\mathrm{p,i}}\frac{\partial C_i}{\partial X} = -\Lambda\frac{C_i}{A_i}, \quad \sum_{j=0}^{i-1} D_j \le X \le \sum_{j=1}^{i} D_j,\ 1 \le i \le m,$$

and

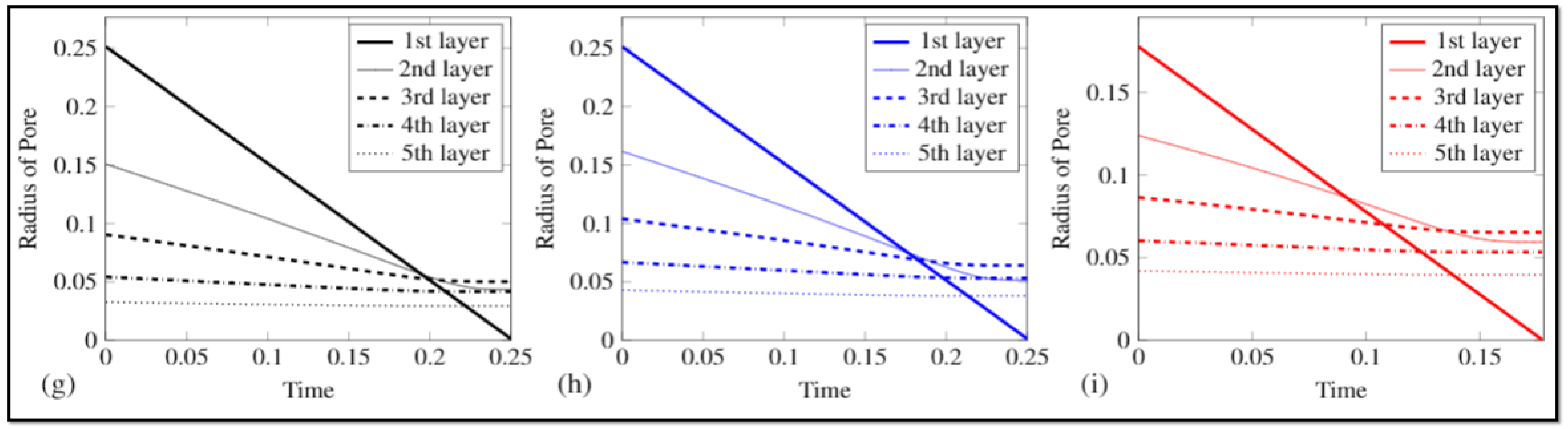
$$\frac{\partial A_i}{\partial T} = -\Lambda\alpha C_i, \quad 1 \leqslant i \leqslant m,$$



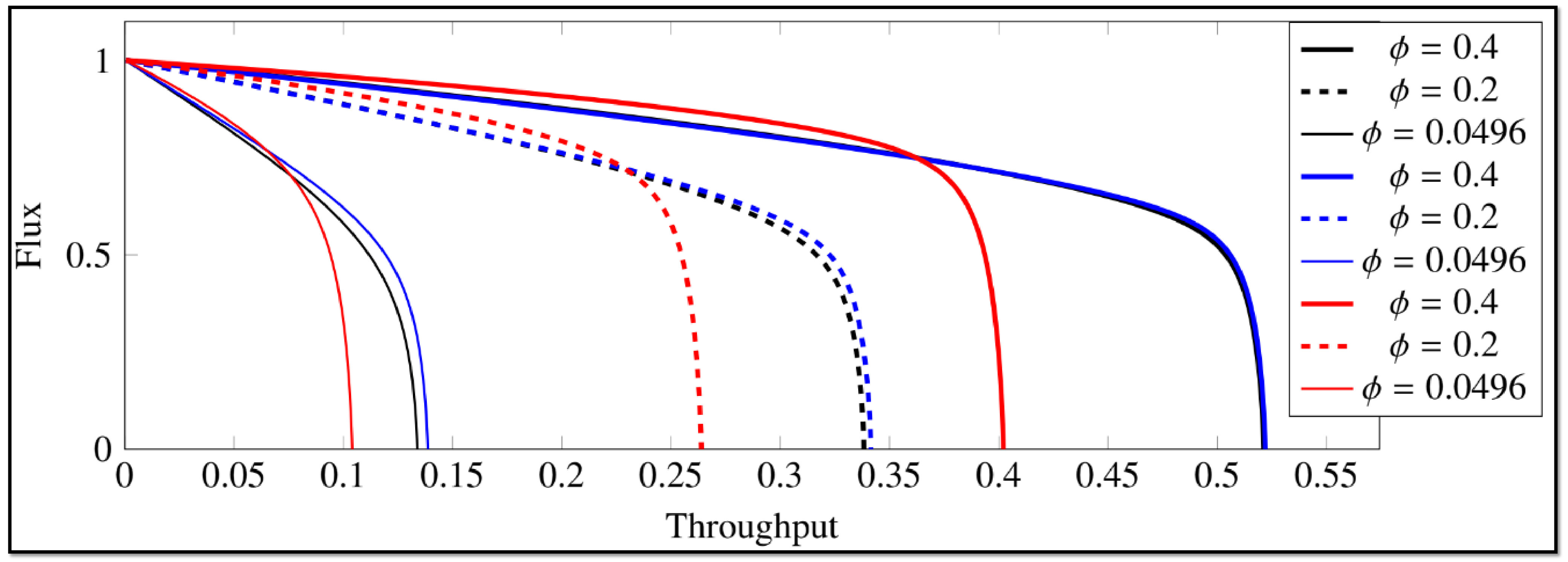
(Left) The three different membranes considered. (a) Two-inlet connected, (b) single-inlet connected, and (c) single-inlet non-connected membranes.

Results

NOTE: Curve colors correspond to single-inlet non-connected (black), single-inlet connected (blue), and two-inlet connected (red) membranes. Lowercase parameters are non-dimensional.

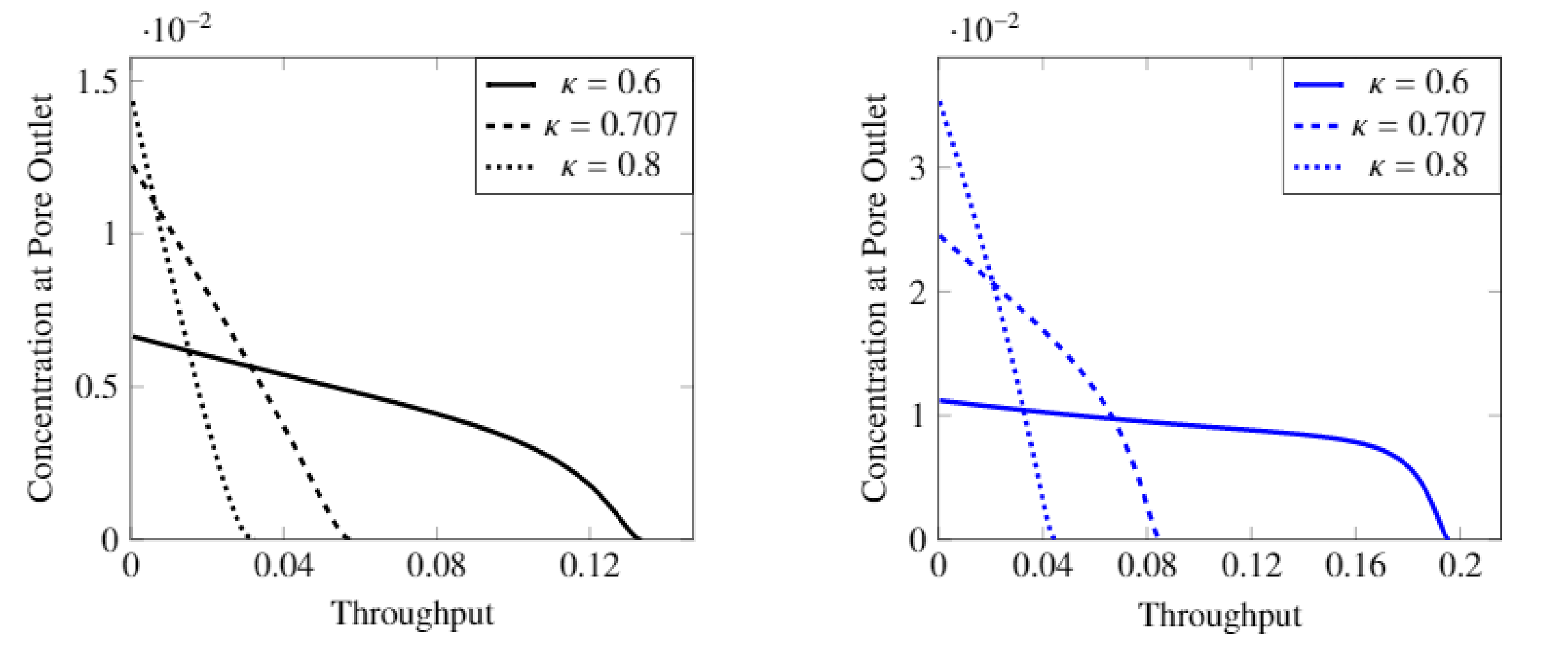


1) (above) Pore radius evolution for each layer with equivalent top layer porosity (ϕ_{top}), layer number $m = 5$, attraction coefficient $\lambda = 30$, and initial resistance $r_0 = 1$. For equivalent ϕ_{top}, single-inlet models exhibit the longest membrane lifetimes.



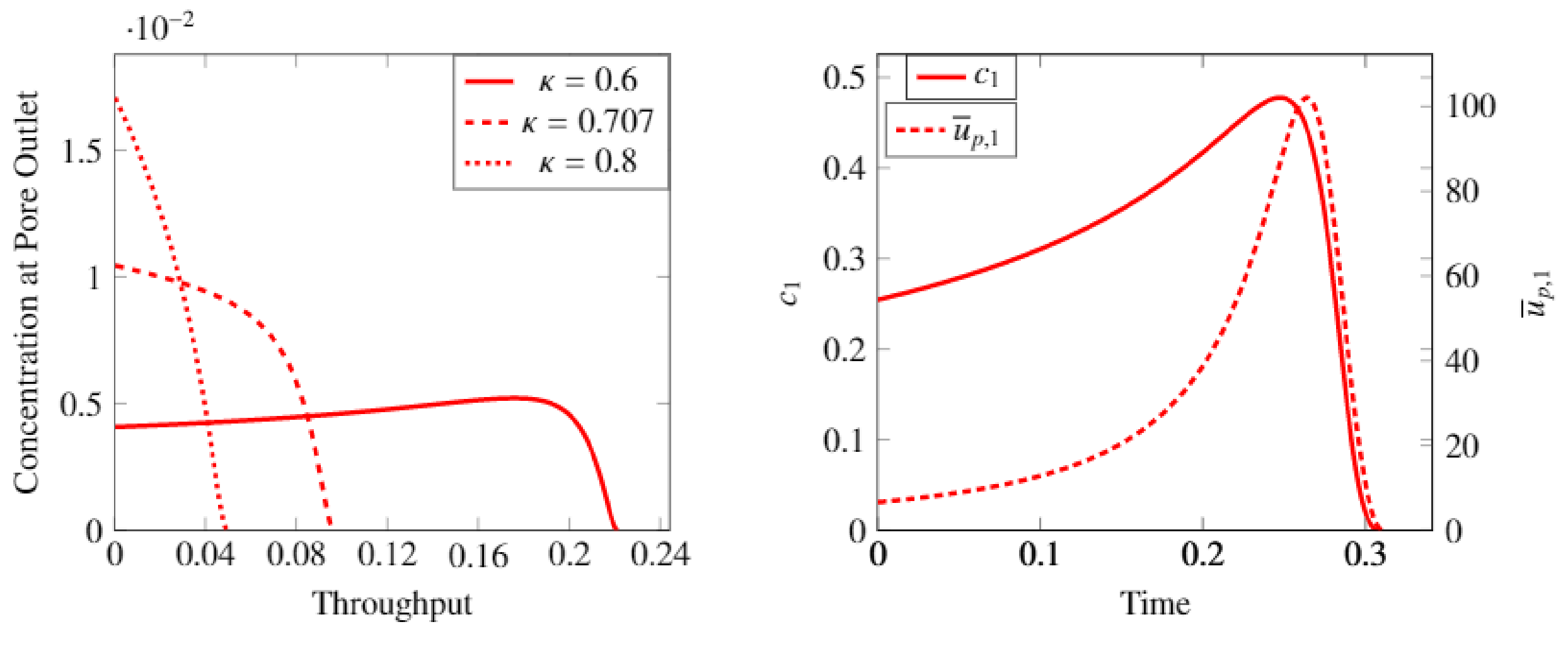
2) (above) Flux versus throughput for equivalent ϕ_{top}, $m = 5$, $\lambda = 30$, and $r_0 = 1$. Single inlet models display best overall performance. Relative performance of single-inlet models depends on layer number.

Results, cont.



(a) Non-Connected

(b) Single-inlet Connected



(c) Two-inlet Connected

(d) Two-inlet Connected, $\bar{u}_{p,1}$ and c_1

3) (above) Membrane filtration efficiency changes over time. Behavior of outlet concentration is coupled to morphology.

Conclusion

(1) Our results suggest that for equivalent ϕ_{top}, membranes with more pores in the first layer will perform worse than those with less.

(2) When comparing membranes with same ϕ_{top}, morphologies with the least inlet pores will yield best Flux-Thp results.

(3) Concentration of particles leaving pore can increase with time due to increase in particle advection rate as pores shrink due to fouling.

References

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Email: dlr26@njit.edu