The Effect of Pin Holes of Varying Size and Number

in

Porous Reacting Membranes

A Finite Element Analysis (FEA) Numerical Model

Craig E. Nelson

Nelson Research, Inc. 2142 – N. 88th St. Seattle, WA. 98103 USA 206-498-9447 Craigmail @ aol.com

The Nature of “Pin Hole” Defects

1. They are formed by localized process variation (dust particle “point masking”) and thus their own statistical distribution.

2. They may be assumed to typically be 5 to 20 times larger than “normal” membrane pores.

3. They are assumed to be “rare”, with only a few pin holes per cm^2 of membrane area..

How do Pin Holes Harm Performance ?

1. They demonstrate imperfect control of the fabrication process environment in an exasperating manner.

2. They "rob" surrounding nearby porous reacting regions of reactant flow.

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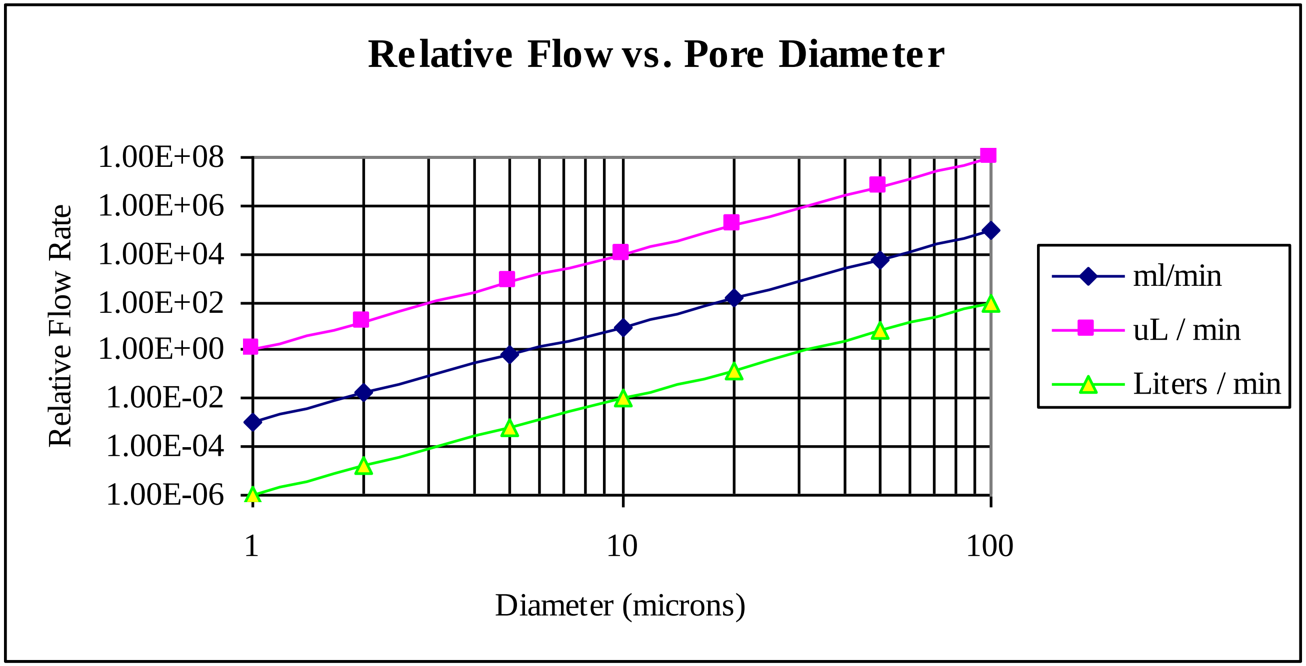
Calculated Flow Volume Results For Membranes with One Pore Size

Flow through a pore goes up as the fourth power of pore diameter !!!!

Therefore: if Q = 10 ml/min for a membrane with 10micron diameter pores
we get the following data plot for flow with other pore diameters



The Deleterious Effect of Large Pin Holes is Truly Amazing

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Diameter (microns)	Flow (ul/min)	Flow (ml/min)	Flow (liters/min)
1	1	0.001	0.000
2	16	0.016	0.000
5	625	0.625	0.001
10	10,000	10.000	0.010
20	160,000	160.000	0.160
50	6,250,000	6,250.000	6.250
100	100,000,000	100,000.000	100.000

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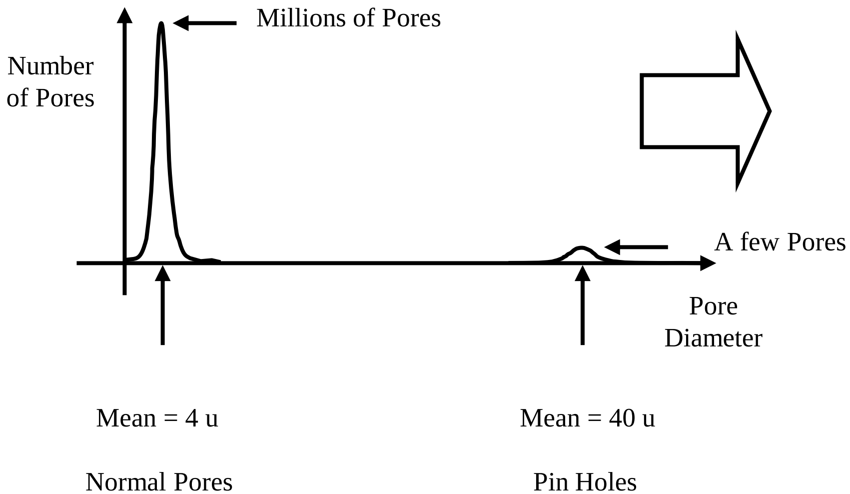
Now We Look at Flow Resulting

from Combinations of both

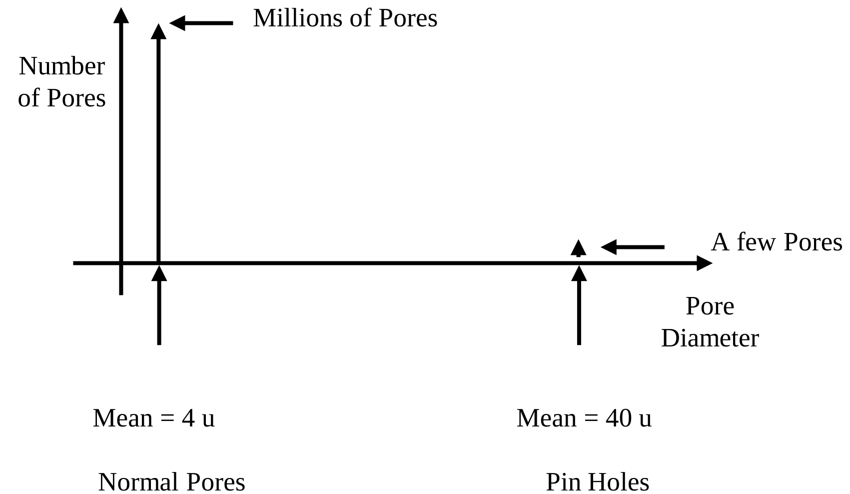
Standard Size and Large Hole Diameters

Total Flow – The Combination of Two Pore Diameter Distributions

(A Simplified But Quite Useful Analysis Approach)



Actual Pore Size Statistical Distribution



Idealized Pore Size Statistical Distribution

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Using The Following Ratios Simplifies the Analysis

1. The ratio of pin hole diameter to regular pore diameter : Diameter Ratio

   Diameter Ratio = Pin Hole Diameter / Normal Pore Diameter

2. The number of pin holes divided by the total number of pores : Nbig Ratio

   Nbig Ratio = Npin holes / (Nnormal pores + Npinholes)

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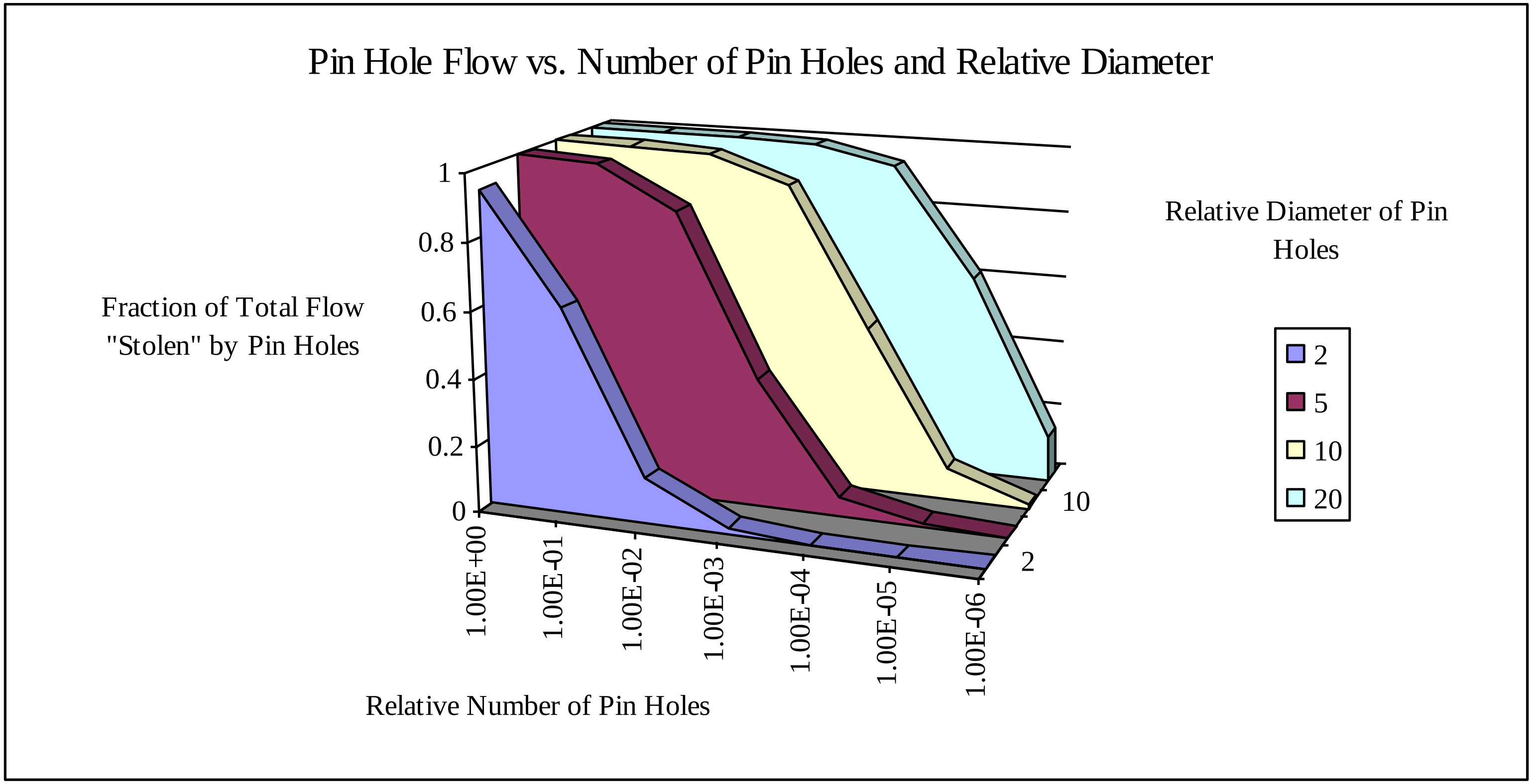
The Effect of a Mixture of Normal Pores and Pin Holes in a Membrane



Apparently one or two 20 x normal pin holes per cm^2 “steal” about 15% of the total flow

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The Effect of a Mixture of Normal Pores and Pin Holes

Relative number of big pores to small pores	Relative dia. of big pores to small pore dia.	Pinholes per cm^2	Fluid Conductivity ratio of big pores to the total of all pores
1.00E+00	10	-	1.000
1.00E-01	10	-	0.999
1.00E-02	10	-	0.990
1.00E-03	10	-	0.909
1.00E-04	10	150	0.500
1.00E-05	10	15	0.091
1.00E-06	10	1.5	0.010

Relative number of big pores to small pores	Relative dia. of big pores to small pore dia.	Pinholes per cm^2	Fluid Conductivity ratio of big pores to the total of all pores
1.00E+00	20	-	1.000
1.00E-01	20	-	1.000
1.00E-02	20	-	0.999
1.00E-03	20	-	0.994
1.00E-04	20	-	0.941
1.00E-05	20	15	0.615
1.00E-06	20	1.5	0.138

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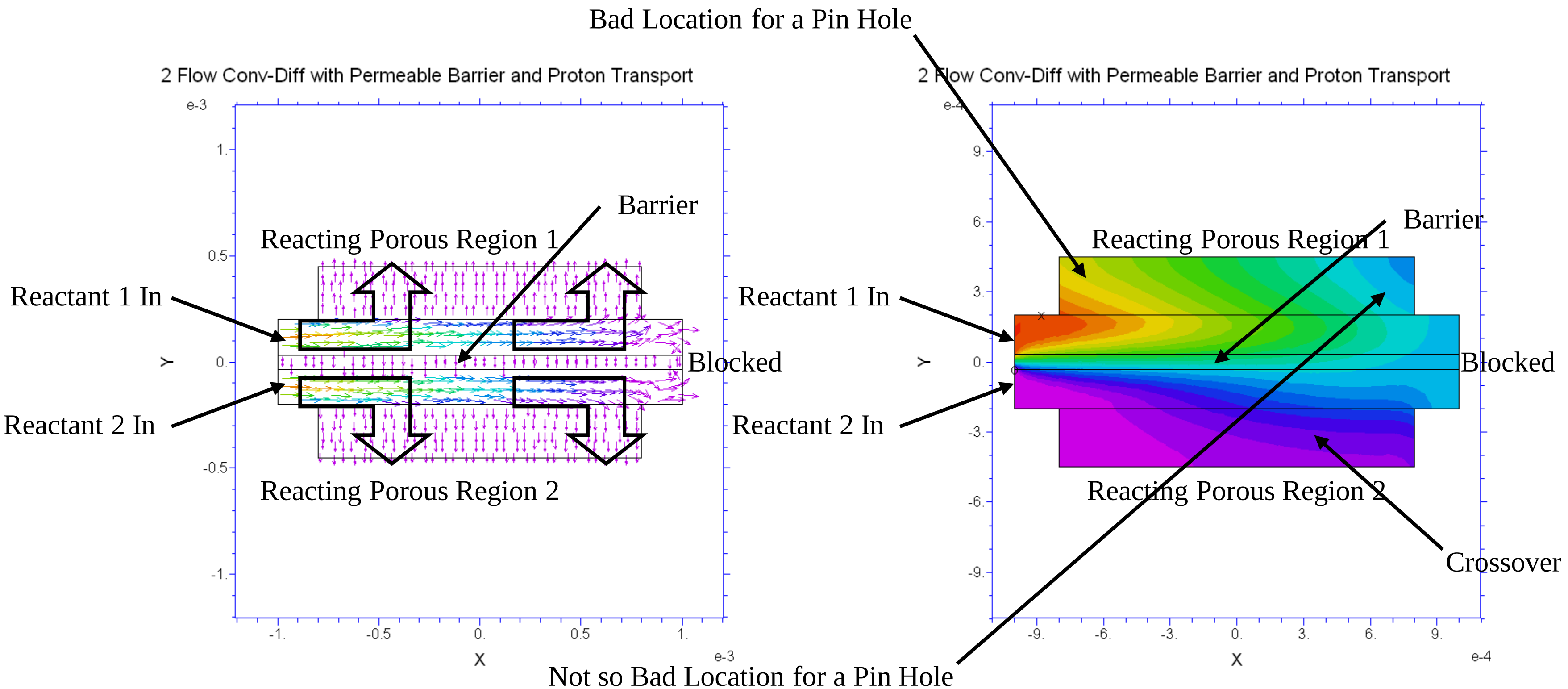
Variation in Reactant Concentration in a Complex Domain with "Inside Out" Single Phase Fluid Flow



Fluid Flow Vector

Reactant 1 Concentration

Large Pin Hole Location Could Matter When Concentration Gradients are Present

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Conclusions

1. Large (50x) pin holes are a disaster and can not be present in viable membranes

2. A few 5x-10x pin holes per cm^2 is probably OK

3. Location of pin holes should be tracked. Pin holes on the inlet end of membranes may be expected to have a larger effect on performance than same sized pin holes on the outlet end of reacting membranes

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