# The relationship between permeability and the number of cells embedded in a microfluidic device

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# Introduction

As micro fluidic devices get smaller everyday, optimizing such small devices are becoming more difficult each day. One new approach for optimizing such small devices is through computer simulations using software such as FEMLAB. In this particular case the interactions of nanoparticles on cells imbedded in gel were studied. The goal is to develop a model that would describe the experiment and could be used to improve the design. One area of interest was how the permeability would change depending on the number of cells embedded and how the injected nanoparticles would travel across the porous gel.

To simplify the simulation model, a 2-D model was used and the following assumptions were made:

- The liquid containing the particles injected into the gel has properties of water ( density, viscosity, etc)
- The flow is induced by a pressure gradient.
- Insulation/Symmetry boundary conditions

Several simulations were done with different number of cells, and the permeability of each run was calculated using Darcy's Law. The parameters for Darcy's Law were obtained from standard literature values and using the properties of water. A control simulation with no cells was done to verify the simulation was running correctly before proceeding with the rest of the simulations; the permeability calculated from the control simulation was compared with the permeability that was inputted to verify the simulation was running correctly.

## Set up

A number of simulations with different number of cells were done, however this report will explain only one run in detail for example.

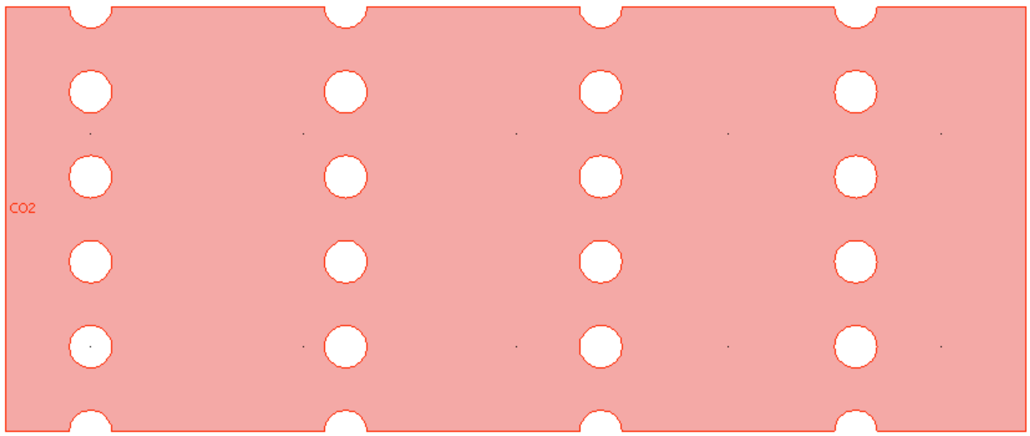


Figure 1. Simulation with 20 cells embedded

Figure 1 represents the set up for a 2-D simulation done with 20 cells embedded. Each boundary condition for the cells is set to insulation/symmetry. Darcy's Law was used to develop this model. The equation for Darcy's Law in FEMLAB is:

$$\rho \cdot \mathrm{u} = -\frac{\rho\kappa}{\mu}\nabla \mathrm{p}$$

Standard literature values for water were used to carry out the computations, where the various quantities were:

$$\rho = 1 \text{ g/cm}^3 \text{ (density)}$$

$$\kappa = 1.5 \text{ x } 10^{-14} \text{ cm}^2 \text{ (permeability)}$$

$$\mu = 0.01 \text{ g/cm\_s (dynamic viscosity)}$$

$$\text{p} = 1 \text{ pa (pressure)}$$

And the following quantity was calculated by FEMLAB:

u = cm/s (velocity)

To check if the simulations were running properly the simulation with no cells embedded was done first, and then the permeability was calculated by rearranging the equation for Darcy's Law using the velocity calculated by FEMLAB. The calculated permeability was compared with the literature value inputted in the beginning of the simulation and was found to be identical, thus verifying the simulation was running correctly.

# Results

A simulation with no cells embedded was done first to verify the simulation was running correctly.

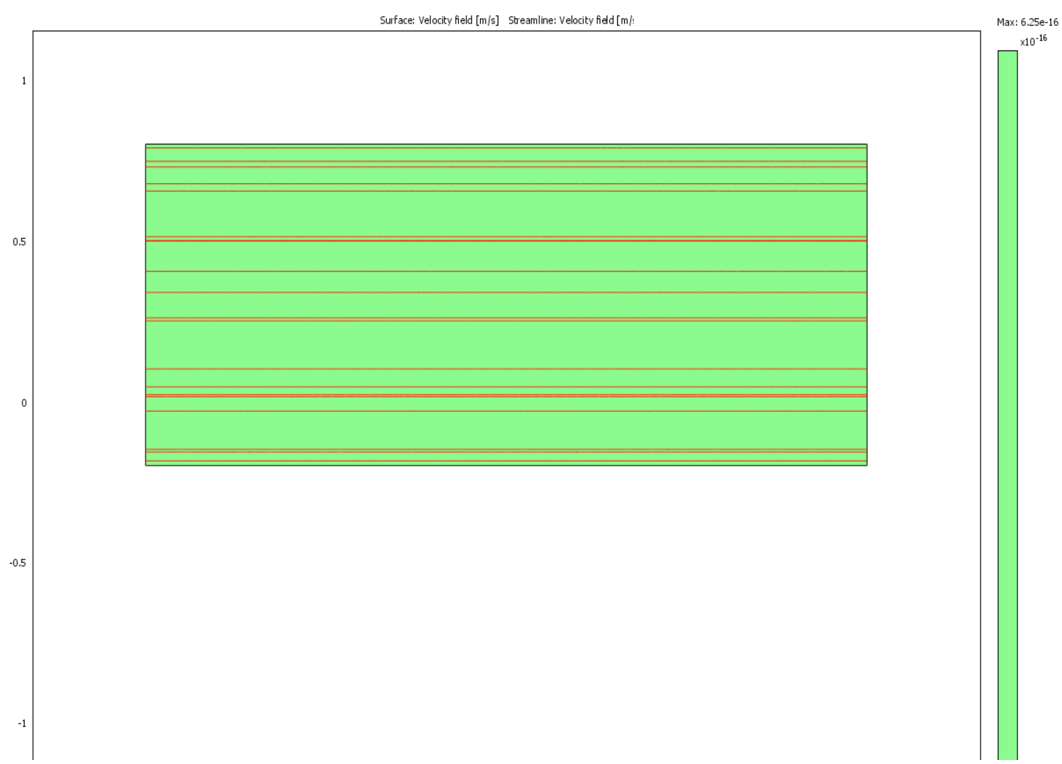


Figure 2. Simulation with No Cells Embedded

The results showed no variation in color because the velocities of each particle remained constant as it moved across the gel; since there were no cells embedded that would cause the velocity to change. Also the red stream lines representing the particle pathways were linear since there were no cells embedded to cause an obstacle for the particles.

Figure 3 is an example of one of the results obtained from simulations.

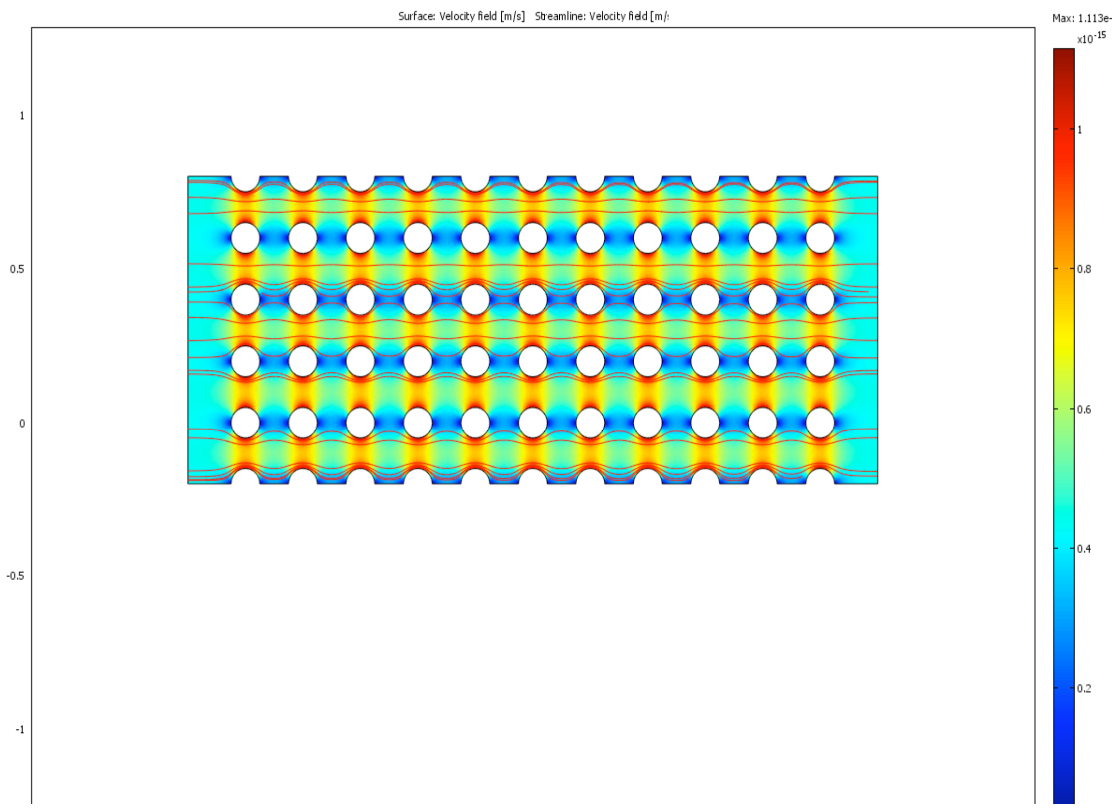


Figure 3. Simulation with 55 Cells Embedded

The red stream lines represent the particle pathways as the particle moves throughout the porous gel. The different colors represent different velocities of the particles. The velocities of the particles between each cell decrease significantly compared to the velocity of particles that have no cells in its pathway. This is because in the region between the cells, the particles are moving by diffusion hence the particles are moving significantly slower compared to other particles.

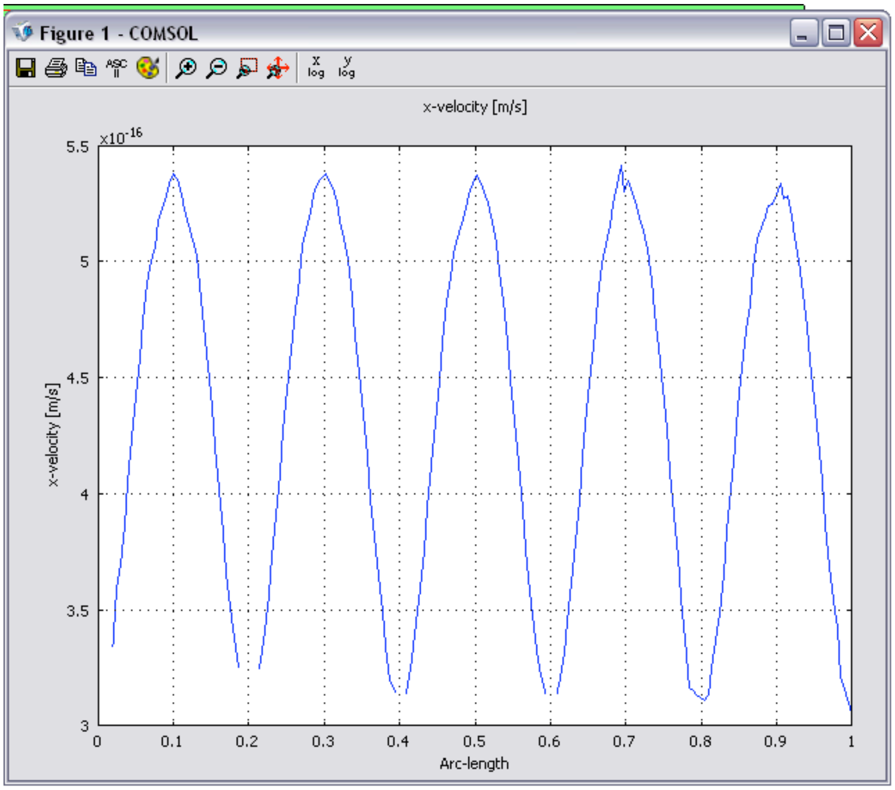


Figure 4. Velocity profile of a Cross Section of the Gel.

Figure 4 shows the velocity profile through a cross section of the porous gel material. The velocity profile shows a repeated pattern of the velocity increasing and then decreasing as the particle moves across the gel. This is again because of the particles are moving by diffusion the region between cells

Each simulation was done under the same conditions only changing the number of cells embedded within the gel. The numerical results are shown in Table 1.

| | | | | | | |
|---|---|---|---|---|---|---|
| N | 0 | 20 | 30 | 36 | 40 | 55 |
| Velocity (m/s) | 6.25E-16 | 5.36E-16 | 5.01E-16 | 4.85E-16 | 4.75E-16 | 4.31E-16 |
| Dynamic Viscosity(pa*s) | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 |
| Pressure (pa) | 1 | 1 | 1 | 1 | 1 | 1 |
| Calculated Overall Permeability($m^2$) | 1.5E-18 | 1.29E-18 | 1.2E-18 | 1.16E-18 | 1.14E-18 | 1.04E-18 |
| Void Fraction (%) | 0 | 6.541667 | 9.8125 | 11.775 | 13.08333 | 17.98958 |

Table 1. Calculated Permeability for Each Simulation

The change in permeability versus the number of cells was plotted as in Figure 5. The permeability shows an inversely linear relationship with the number of cells embedded; the permeability decreases linearly as the numbers of cells are increases.

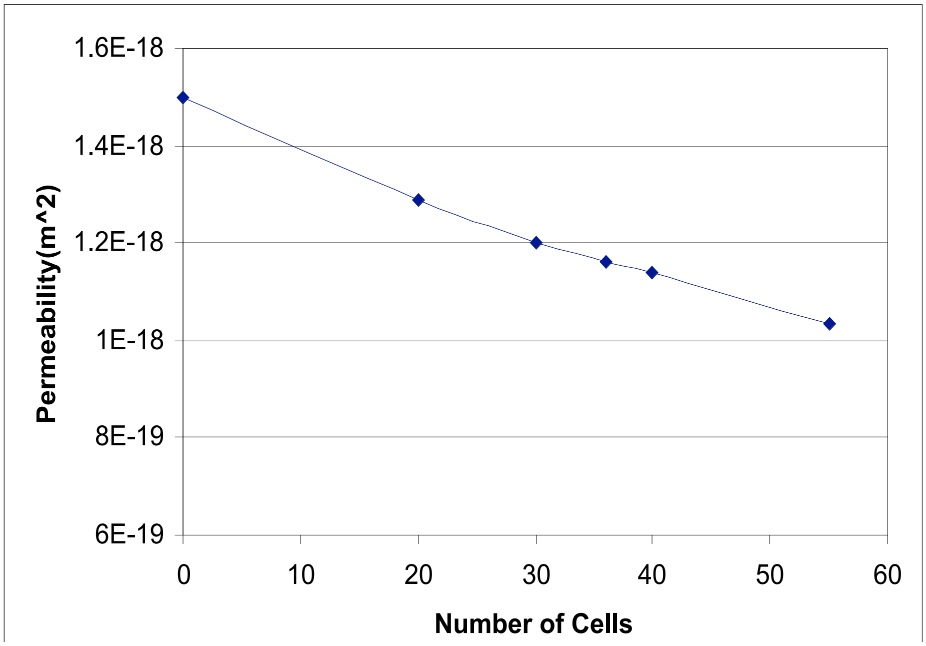


Figure 5. Plot of Permeability vs. Number of Cells Embedded

A simulation to study the change in concentration with respect to time was also done to study the movement of the particles across the porous gel material. This simulation was done by creating an animation showing how the concentration profile changes as time progresses showing how the particles would move across the porous gel material. Figure 6 is a snap shot of the simulation.

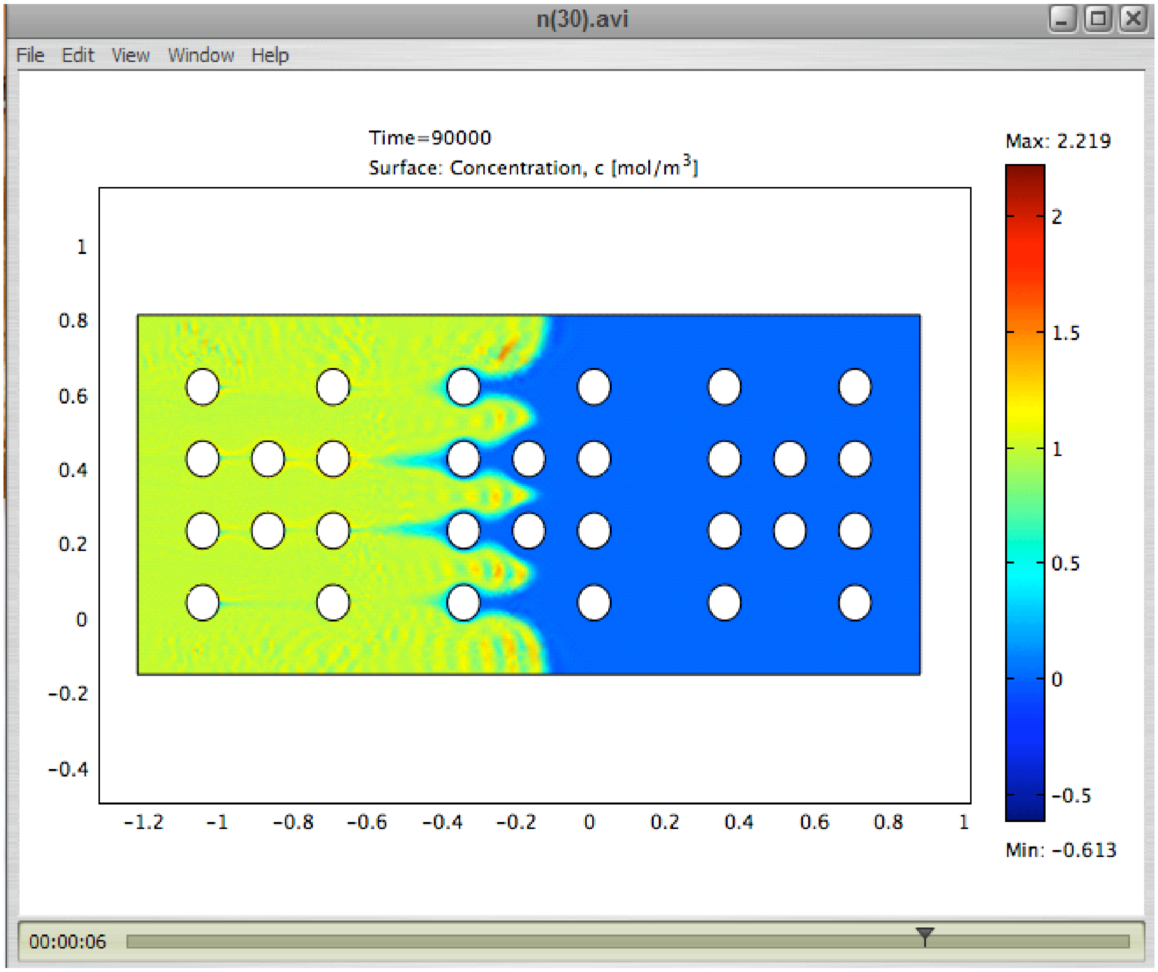

Figure 6. Snap Shot of Change in Concentration

Figure 6 shows the concentration moving across the gel faster in the regions where there are no cells in the pathway of the particles, and the concentration changing much slower in the regions between cells. Once again this is because the particles are moving by diffusion in those regions.

## Conclusions and Recommendations

The permeability clearly shows an inversely linear relationship with the number of cells embedded. As the number of cells embedded increases the permeability decreases proportionally. The velocity of the particles shows a significant decrease in the region between each cell, because the particle is moving by diffusion rather than the pressure gradient in these regions.

For further research I recommend running 3-D simulations to study permeability and movement of particles in more detail in a porous gel material.