Investigating Anomalous Water Flow on the Microscopic Level

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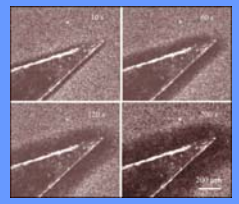
Abstract

Water has shown a remarkable phenomenon when exposed to hydrophilic surfaces – a naturally occurring zone near the surface which excludes any particles in the solution. Upon investigating this exclusion zone, I soon found that one could induce a flow between two reservoirs of initially identical water solutions that were separated by a hydrophilic membrane. Furthermore, by altering the pH of the water on one side of the surface I can dramatically increase, decrease, or even reverse the direction of the flow. My current research is probing the cause of this flow, and the chemical properties associated with it. By approaching the problem from a variety of angles I have been slowly refining my understanding of the chemical and electrostatic forces at work. I believe that within the next few months I should have sufficient data to determine with good confidence the origin of this phenomenon.

Background

Previous research at the Pollack Lab has found that many hydrophilic surfaces exhibit a naturally occurring phenomenon. When immersed in an aqueous solution these surfaces form a solute-free zone in the nearby water – an Exclusion Zone. This zone is theorized to be caused by the structuring of water molecules into hexagonal formations, which extend far (>0.5mm) beyond the material surface. The exclusion zone only forms near hydrophilic surfaces; hydrophobic materials show no such zone. Additionally, the zone exhibits a strong negative electrical potential which decreases exponentially with distance from the surface, becoming positive at large distances. This knowledge has helped shape my hypothesis and enhanced my understanding of the forces at work in this research project.

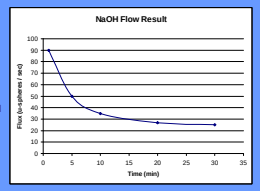


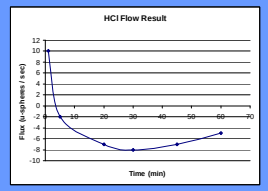
The Exclusion Zone (dark region) grows around a Nafion film submerged in a microsphere solution (white particles). From Pollack and Zheng et al, 2006

Interesting Results from Varying pH

- The results from the two-hole experiment seem to indicate that the exclusion zone may be playing a part in causing this flow to occur. To test this I began artificially altering the exclusion zone by changing the pH of the solution inside the tube.
- Past research has shown that the exclusion zone is negatively charged. My theory was that by introducing H+ to the solution we should be able to neutralize some of that negative charge and in effect reduce the size of the exclusion zone.
- This theory proved correct; by adding HCl I could reduce the exclusion zone from >100um to 10um or less. At the same time, by adding a base NaOH I could grow the exclusion zone to ~1mm. I could now begin testing whether exclusion zone size effected flow rates.
- The results are very conclusive here. Using NaOH increased the flow inward dramatically. Instead of diminishing to a rate of 2-3 microspheres / sec it stayed up around 20-25 microspheres / sec (see below, left).
- The results from acid tests are even more interesting. I had predicted that a shrunken exclusion zone would merely disable or diminish the flow inward. Instead the water stopped and then reversed direction.
- This reversal is perhaps the most interesting phenomenon of this research project. None of my theories can account for it perfectly.

The results from altering the pH of the reservoir solution. Adding a base (NaOH, left graph) dramatically increases the inward flow. Adding an acid (HCl, right graph) produces an interesting result. The flow starts inward as usual but quickly stops, reverses and flows back out. Positive flux indicates an inward flow.





a

b

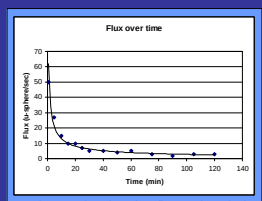
These photographs show the process by which flow occurs. A Nafion tube is submerged in a microsphere solution and an exclusion zone begins to form. Next (**a**) a glass needle is used to poke through the Nafion tube wall (horizontal band) creating a 150um hole. A photo (**b**) taken 15 minutes later shows the flow in progress. The water naturally prefers to flow from outside the tube (bottom) to the inside (top)

Notice the exclusion zone (clear area) in both photos, and how it changes over time

Unexpected Water Flow

The genesis of this research project stems from an observation made in the Pollack Lab a few years ago. A tube of Nafion – a hydrophilic Teflon-based plastic – was placed in a water reservoir and completely immersed inside and out. After allowing the exclusion zone to form, a small hole was poked through the wall of the tube using a fine glass needle (photo above, **a**).

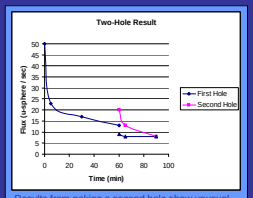
What was found was that the water naturally and consistently flowed from the outside of the tube to the inside. This was highly unexpected, as the water inside and out appeared to be identical. It was also seen that the flow – measured by watching microsphere indicators in suspension – dropped off over time yet never fully stopped even after hours of observation (see graph at right). From this early observation I have been probing the cause of this flow and have found several interesting results and observations.



Results measuring microsphere flux over time. Flux is proportional to water velocity through the hole, where positive flux indicates an inward flow.

Observations and Results

- First and foremost, this is not a simple hydrostatic-pressure-induced type of flow. Experiments have been run using tubes of different materials such as Silicon, which do not produce exclusion zones. These tests have been nearly identical to the original experiment in terms of depth of submersion and tube size, and yet they fail to produce any flow whatsoever. If gravity were the cause of this flow, surely these tubes would see a flow as well. Clearly there is something else going on.



Results from poking a second hole show unusual results for both holes

- There is a clear volume change inside the tube, showing that water is indeed flowing in, not just the microsphere indicators.
- An unusual thing happens when a second hole is punched in the tube wall. The graph at left shows the flow rates for each hole both before and after a new hole is punched some distance away from the first.
- The flow through the original hole decreases dramatically, and the new hole experiences a flow greater than that which was seen in the original hole. Both flows begin to even out over time, eventually reaching a similar rate
- The data seems to indicate that the exclusion zone plays a role in this unusual behavior. The illustration at right shows the relative sizes of the exclusion zone near the original hole and near the second hole, yet to be punched by the needle.
- This theory would explain why the second flow is greater than the first, and why the flows all slow down over time. If the exclusion zone shrinks perhaps there is less of a "pull" to induce the flow. This was investigated in great depth using acids and bases.

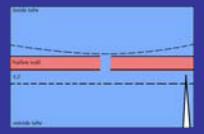
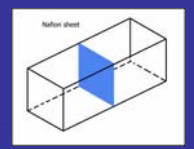


Illustration showing exclusion zone size along the tube, and the needle used to punch new holes

Current Research and the Future of the Project

- For the past several months I have been attempting to isolate the cause of this flow. My current research has been trying to replicate the results from the tube experiments using a larger, more general test.
- I have been using a Nafion sheet to represent the tube wall. This sheet is held between two large reservoirs of water which represent the inside and outside of the tube (see diagram at right). By artificially altering the conditions on either side I hope to reproduce the conditions which allowed for flow as seen in the tube.
- By isolating various factors I should be able to determine what exactly is responsible for the flow and what is not.
- So far my results have been inconclusive. It may be the case that this new reservoir is too deep for a suitable exclusion zone to develop, as exclusion zone has already shown to be a factor in flow rate.
- I hope to be able to wrap up my project in the coming months and begin working on a manuscript for publication.



UW Undergraduate Research Program

University of Washington College of Engineering Bioengineering

Special Thanks to: Ivan Klyuzhin, Hyok Yoo, Adam Wexler, Ronnie Das