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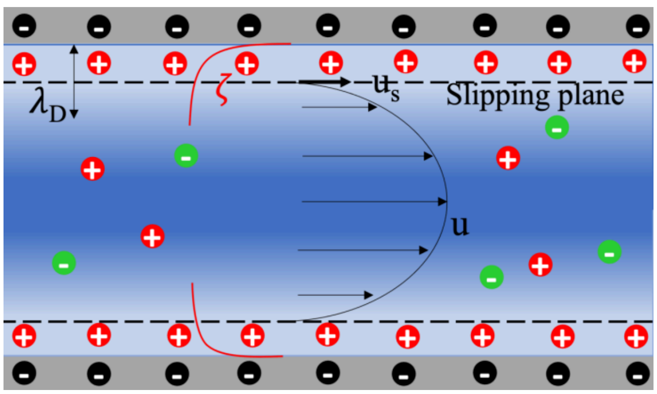
Individual Component Analysis - Materials

Project Background:

As water moves over a surface, it is well known that a boundary layer forms and the dynamics of that boundary layer are well studied. If, however, the fluid is not pure water and instead a homogeneous electrolyte such as salt water and the surface possesses even a slight electrical charge, a second type of boundary layer forms known as the Stern layer.



This layer consists of the opposing ions (for example Na^+) from the dissociated electrolyte in the water which are attracted to the charge of the surface. As the fluid velocity and pressure drop increase, the force of attraction between these ions and the surface becomes relatively larger than the dissociated ionic bond between the Na^+ and Cl^- which results in a measurable physical separation between them in the fluid. This separation, when multiplied over many ions across a large surface, can now be interpreted as a measurable potential difference yielding, in effect, a battery.

The driving equation behind this phenomenon is:

$$V_s = \frac{\epsilon_o * \epsilon_r}{\sigma\eta} * \Delta P * \zeta$$

Where V_s is known as the streaming potential, ϵ_o is the permittivity (dielectric constant) of a vacuum, ϵ_r is the permittivity of the fluid, σ is the conductivity of the the fluid, η is is the viscosity, P is the pressure drop across the channel, and ζ is known as the zeta potential.

The project, sponsored in conjunction by Professors Bandaru lab and Palaemus Oceanic, seeks to support their application for the InDEEP competition hosted by the department of energy. Our work focuses on moving the project from the lab research phase to the product development phase, packaging what is a now bulky bench setup into discrete modules that can be used in the field. Not only do we have to scale the channel from a test-bed that is micrometers tall, we need to design for survivability and modularity in use cases.

Functional Requirements:

From the streaming potential equation, we can see that most of the factors in the generated voltage are physical properties of the environment, and thus fixed. The only two that we have control over is the zeta potential and the pressure drop. Pressure drop is largely controlled by the geometry of the channel and the flow rate of fluid through it and our goal is to operate between 1 and 100 KPa of pressure. Zeta potential, however, is a more abstract value and is not clearly defined. It is only obtainable experimentally, and simply serves as an indicator of the attractive force between the surface and the dilute ions. However, through experiment, the Bandaru lab has identified a correlation between dielectric properties of materials and their zeta potentials in this application. As such, the key material property driving the voltage generation is the dielectric constant). From a secondary standpoint there are other properties that would be beneficial such as strength, hydrophobicity, and manufacturability.

There are four materials that we have identified as having potential for application on this project.

1. Pure Silicone
2. Alumina
3. Graphene Oxide
4. PDMS

<u>Comparison Table:</u>

Material	Pros	Cons
Pure Silicone	-Dielectric Constant of ~11.7 -Manufacturable with additive and molding manufacturing -Chemically stable and resistant -Highly hydrophobic -Lab has shown that Silicon Wafers work -Inexpensive -Non-conductive	-Harder to get extremely high precision in manufacturing -If not 3D printing, manufacturing mostly limited to sheets and tubes
Alumina	-Dielectric Constant of 9.8 -Extremely high strength ceramic -Very chemically stable and resistant to solvents and abrasives -Extremely precise 3D printing	-Extremely expensive -Requires specialty post processing for SLA printer

	-Non-conductive	
Graphene Oxide	-Extremely high dielectric constant (can be up to 10^6) -Nanotubes can be manufactured, yielding extremely high surface area-volume ratios -Can be embedded in other materials -Non-conductive	-Dielectric constant is shown to vary with humidity -Not structurally viable alone, must be part of composite -Complex material with manufacturing methods likely out of our capability
PDMS	-Industry Standard for microfluidics -Manufacturable by hand with high precision -Flexible, high strength -Lab has proved PDMS-only channels have worked -Non-conductive -Inexpensive	-Bulk manufacturability very low -Dielectric constant of ~2.8

Material choice is the foundation of this project with the potential to make or break the success of our prototypes. Manufacturing methods, biofouling concerns, test-bed design, and channel designs are all contingent on the unique properties of the material that we select. For the time being the most viable material that we are exploring is Silicone due to its high dielectric constant and access to 3D printers that are capable of printing this material with no additional post-processing needed.

References:

Phone Calls/Emails:

1. Jeremy Reid:
   Phone: (336)-803-1940
   Email: jreid@palaemus.com
   I spoke with Jeremy on two zoom calls regarding the details of the DOE competition, and Palaemus's needs for the product, as well as got a better understanding of the physical environments and end goal use for the product.
2. Prabhakar Bandaru
   Email: pbandaru@ucsd.edu
   Not only the project sponsor, Professor Bandaru is also an expert in fluid dynamics and materials science. Meeting with him both in person and over zoom was instrumental in

understanding the driving science behind this project, which will dictate all of our design choices moving forward.

Works Cited
[1] Zhao, X., Shen, D., Duley, W.W., Tan, C. and Zhou, Y.N. (2022), Water-Enabled Electricity Generation: A Perspective. Adv. Energy Sustainability Res., 3: 2100196. https://doi.org/10.1002/aesr.202100196
[2] Dielectric Polarization. (2022, July 28). https://eng.libretexts.org/@go/page/88156

[3] Gavish, N., & Promislow, K. (2016, July 1). Dependence of the dielectric constant of electrolyte solutions on ionic concentration- a micro eld approach. https://arxiv.org/pdf/1208.5169

[4] Kab USA. (n.d.). Dielectric Constant Chart. https://www.kabusa.com/Dilectric-Constants.pdf

[5] Yang, C., Wang, H., Bai, J. *et al.* Transfer learning enhanced water-enabled electricity generation in highly oriented graphene oxide nanochannels. *Nat Commun* 13, 6819 (2022). https://doi.org/10.1038/s41467-022-34496-y