Effects of Nanopore Dimensions on Pressure-Driven Power Generation
Katie Lu1,2, Yixin (Vera) Xu2, Chuanhua Duan2
1Central High School, 423 E. Central St., Springfield, MO, 65802;
2Department of Mechanical Engineering, Boston University, Boston, MA 02215

Introduction
- Nanopores and nanochannels have become increasingly important in the fields of biosensors, membranes for filtering, desalination, and energy generation.

![Diagram of pressure-driven flow through a charged nanopore](image)

- The structure of counter-ions inside the pore attracted by the charged surface is called the electrical double layer (EDL). The heavy presence of counter-ions carries an electrical charge through the EDL.
- However, there are many factors that affect the magnitude of the electrical charge that have not been considered such as the length and diameter of the nanopore. As length decreases, the entrance resistance becomes larger relative to the resistance inside the pore. As length increases, the opposite is true.
- Additionally, surface charge on the reservoir that affects the conductance inside the pore has not been considered.

![Diagram of axisymmetric geometry](image)

- The objective of this study is to understand the effects of nanopore diameter and lengths on streaming current, voltage and maximum power generated by pressure driven ion transport.

Materials and Methods
- Model built using COMSOL Multiphysics
- Used 2D Axisymmetric geometry
  - More accurate than 2D, revolves around an axis to create 3D model
- Used 3 physics to simulate flow through a nanopore
  - Creeping flow (spf)
    - An inlet with a laminar flow boundary condition (AB)
    - An outlet with a laminar flow boundary condition (GH)
  - Electrostats (es)
    - Grounded wall AB
    - Surface charge density on walls CD, DE, and EF
    - Volume force in all domains (1, 2, 3)
  - Transport of dilute species (tds)
    - An inlet with a laminar flow boundary condition (AB)
    - An outlet with a laminar flow boundary condition (GH)
- Initial values
  - Pressure difference of 4 bar
  - Surface charge density of -3 mC/m²
  - KCl concentration of 1e-5 M
  - Surface charge used on the nanopore walls as well as on reservoir walls closest to pore entrance (see figure 4)
  - Mesh consisted of two free triangular elements with heavier distribution around charged surfaces
  - Governing equations
    - Poisson-Boltzmann equation
    - Nernst-Planck equation
    - Navier-Stokes equations

![Diagram of axisymmetric pressure gradient](image)

- The pore has not been considered for pressure driven transport of ions in nanofluidic channels.
- Streaming currents in a single nanopore (EDL) and its parts contributes to accurate planck equation.
- Surface charge density of mC/m²/m (spf)
- Diffracted light in all domains (1, 2, 3)
- Pressure force in all domains
- Volume force in all domains (1, 2, 3)
- Transport of dilute species (tds)
- An inlet with a laminar flow boundary condition (AB)
- An outlet with a laminar flow boundary condition (GH)
- Initial values
  - Pressure difference of 4 bar
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![Diagram of axisymmetric pressure gradient](image)

- Results
  - Length and size of the nanopore does change the amount of power generated.
  - As length increases, the voltage was found to increase. However, as length increases, current decreased. The trend was followed throughout all diameters.
  - This means that the amount of power generated had a maximum. The maximum power found was at a 300 nm diameter and 85 nm length.
  - These results indicate that the entrance resistance compared to the channel resistance does not have significant effects on power generation.
  - This study contributes to power generation experiments as well as nanopore array studies, as it presents new information about the effects of size.
  - Overall, this study corroborates that nanopores are a renewable, clean source of power generation.

![Example of membrane with nanopores](image)

- Discussion and Conclusion
  - If a membrane of one square meter has 30% of its surface covered in nanopores, the largest power simulated in this study could produce up to 55,173 watts per square meter, enough to power an average California household for 2.87 days at the rate of 7,000 kilowatt-hours (kWh).
  - Because the 300 nm diameter was the largest size tested here and had the largest power output, sizes larger than that should be tested to see when the power output stops increasing.
  - Other further research should include experimental data compared to simulation data, to assess the power lost to the environment.

![Diagram of axisymmetric pressure gradient](image)

References
van der Heyden, Frank HJ, Derek Stein, and Cees Dekker. “Streaming currents in a single nanofluidic channel.” Physical review letters 95.11 (2005): 116104.

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