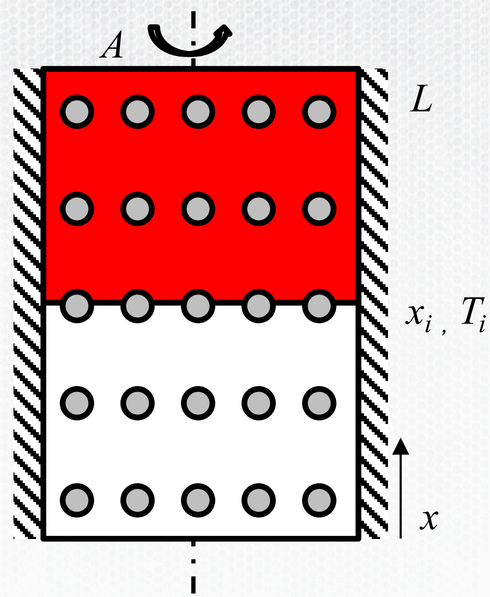
Sodium Pumping via Condensation within a Non-Wetting Porous Structure



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2018 IMECE - Track 10

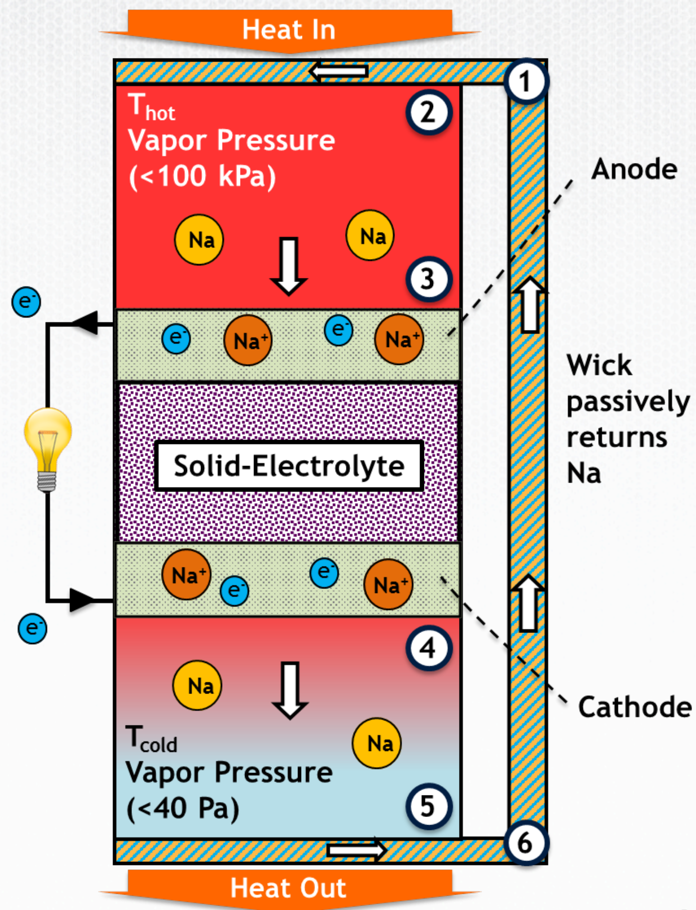
November 15, 2018

Scalable Thermal Energy Engineering Laboratory

Woodruff School of Mechanical Engineering

Motivation

- Liquid metals are used in applications with large heat transfer requirements (e.g. heat pipes, electrochemical systems)
- Goal is to pump liquid sodium in a closed loop system using capillary action
- A large capillary pressure increase in the liquid-vapor interface within non-wetting porous surface is required in the Na-TEC



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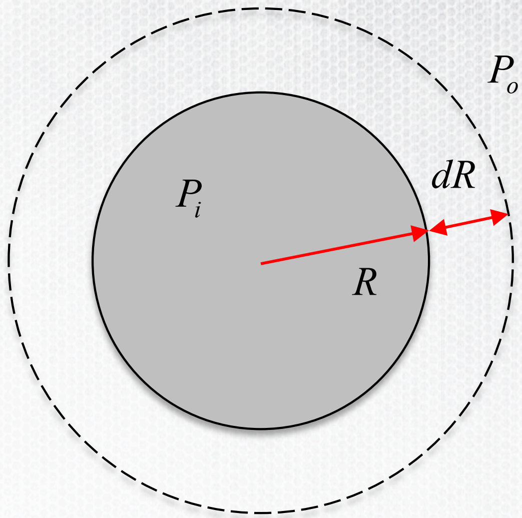
Interfacial Physics

Considering the interface between two fluids, the work required to displace the interface by *dR* is given by:



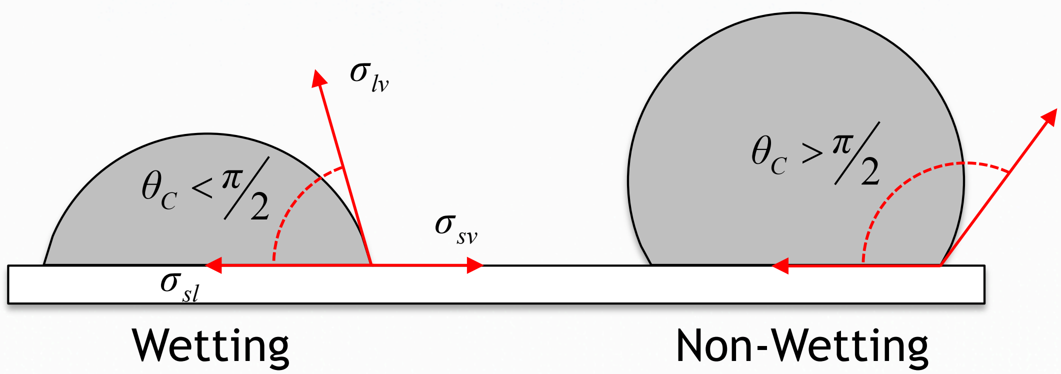
$$\delta W = P_i dV - P_o dV - \sigma dA_s$$

For a sphere at equilibrium:

$$\left(P_i - P_o\right)\left(4\pi R^2 dR\right) = \sigma\left(8\pi R dR\right)$$

Laplace Pressure $\quad P_i - P_o = \Delta P = 2K_{12}\sigma \quad$ where $K_{12} = \frac{1}{2}\left(\frac{1}{R_1} + \frac{1}{R_2}\right) \rightarrow \left(\frac{1}{R}\right)_{sphere}$

Young-Dupree Equation $\quad \sigma_{sv} = \sigma_{sl} + \sigma_{lv}\cos\theta_C$



Conservation of Mass

If mass transfer occurs by advection and diffusion, the two commonly used models are the advection-diffusion model (ADM) and the dusty-gas model (DGM).

Assume a binary mixture within a porous structure:

Conservation of mass
$$\varepsilon \frac{\partial \rho_i}{\partial t} + \nabla \cdot \left[\underbrace{\rho_i \left(-\frac{\kappa}{\mu} \nabla P \right)}_{\text{Advection}} - \underbrace{\rho \varepsilon D_{ij} \nabla \omega_i}_{\text{Binary diffusion}} \right] = 0$$

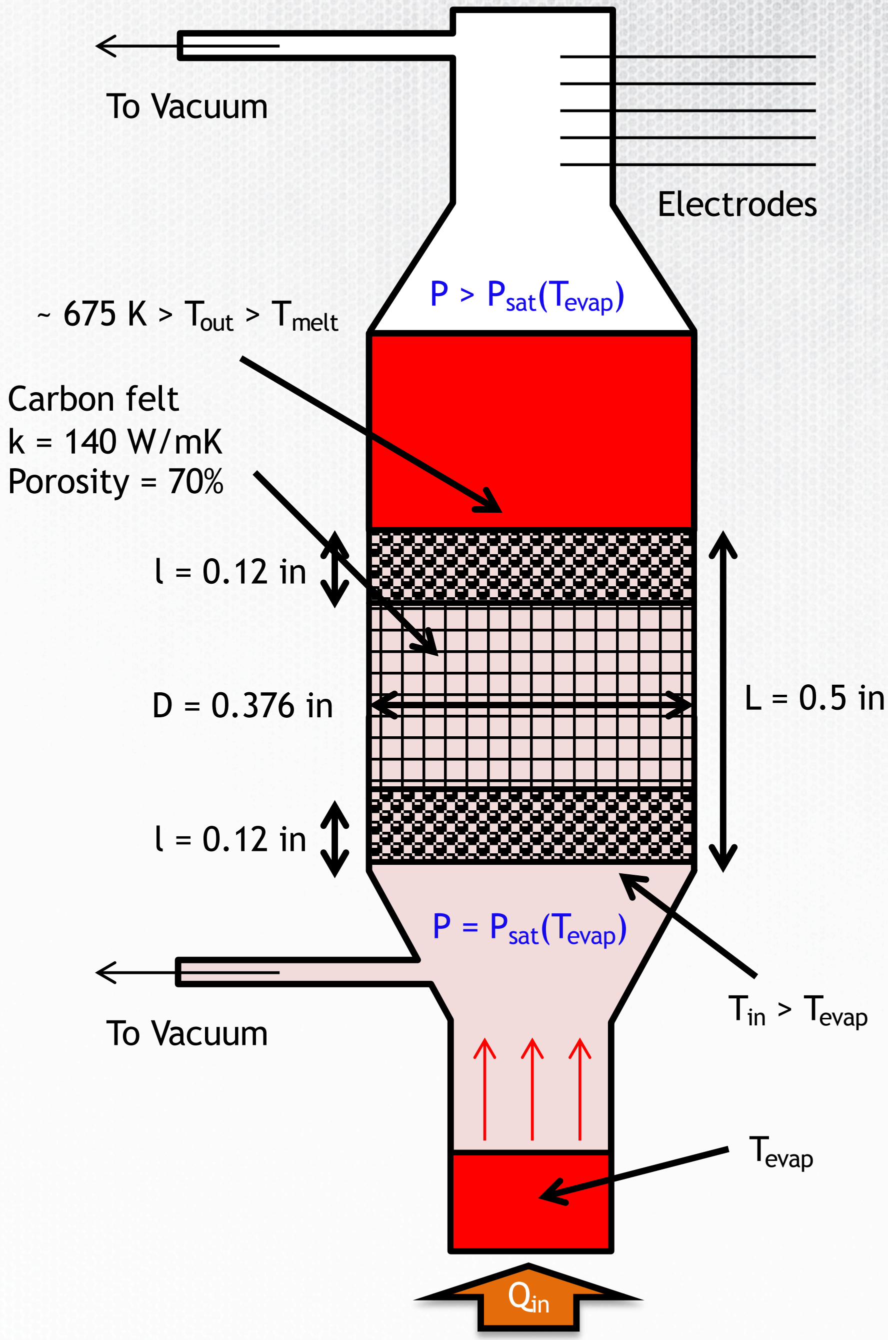
The permeability is given by the Blake-Kozeny expression
$$\kappa = \frac{D_p^2 \varepsilon^2}{150\left(1-\varepsilon^3\right)}$$

To account for Knudsen diffusion, the permeability is modified by the Klinkenberg factor:

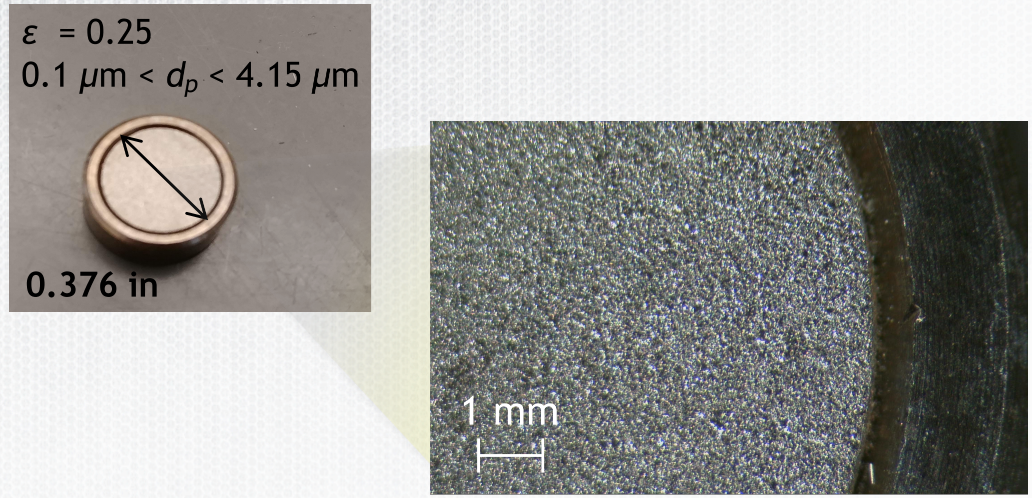
$$\kappa = \kappa_\infty \left(1 + \frac{D_{iK}\mu_i}{\kappa_\infty P} \right)$$

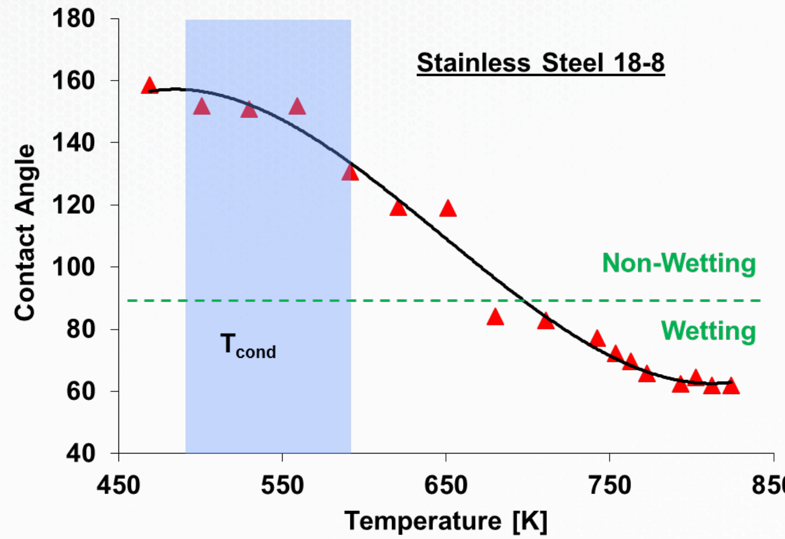
from kinetic theory:
$$\begin{cases} D_{iK} = \varepsilon \dfrac{4}{3} d_{pore} \left(2\pi RT\right)^{-1/2} \\ \mu_i = \rho d_{pore} Kn \left(2RT/\pi\right)^{1/2} \end{cases}$$

Vacuum Pressure Experiment



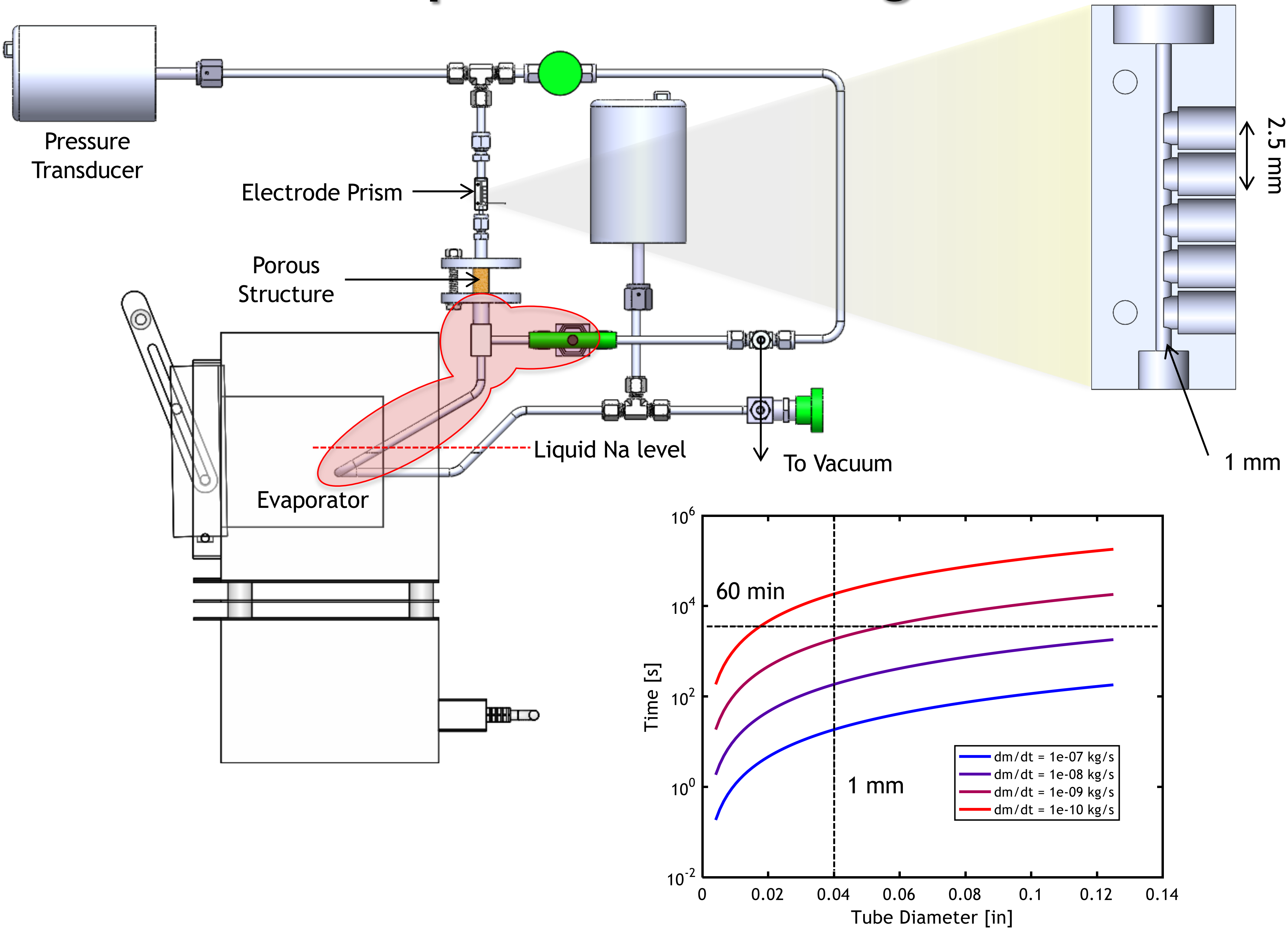
SS 316 thermally pressed inside cylinder





Taylor & Ford, *U.K. Atomic Energy Authority Report*, 1955

Experimental Design

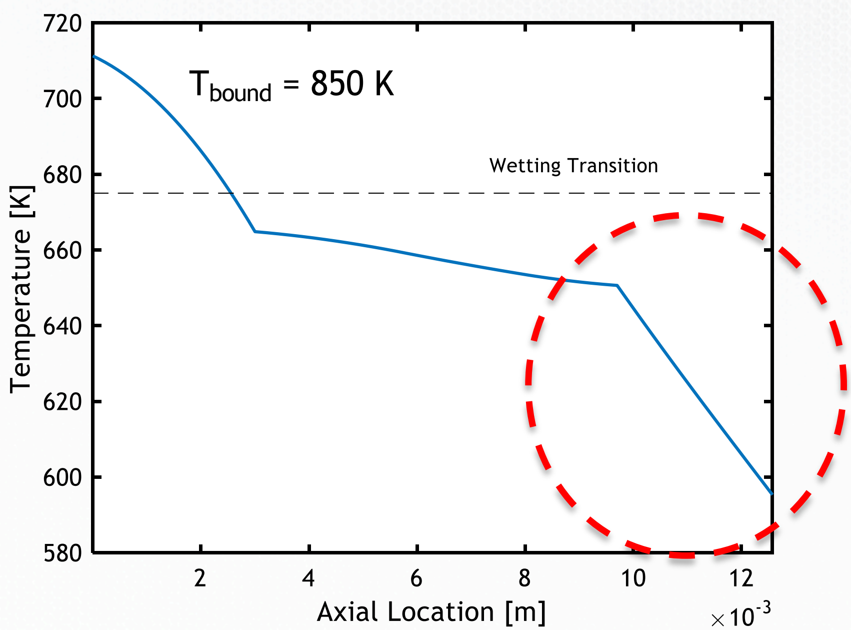


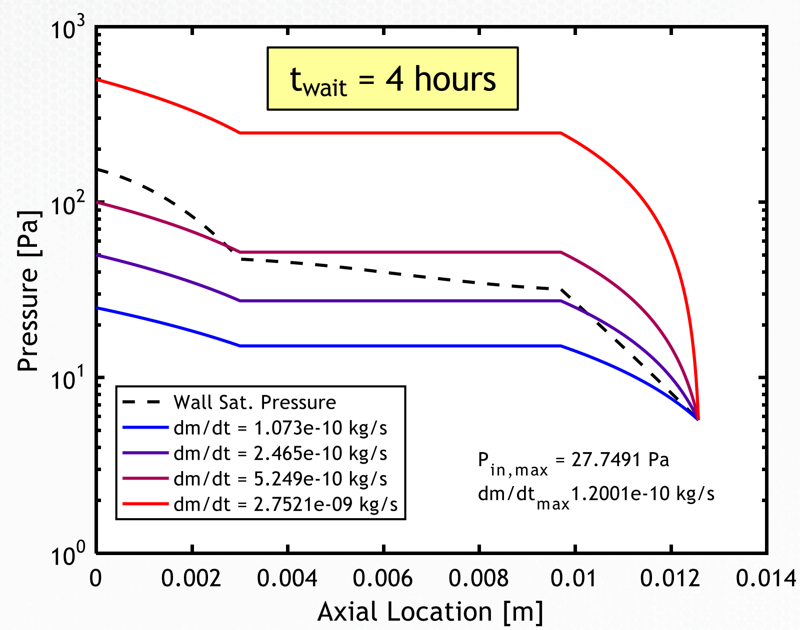
Maximum Mass Flowrate

Assume there is no presence of argon, so transport is just with a single species of sodium vapor. Solve the compressible Darcy equation with the following considerations:

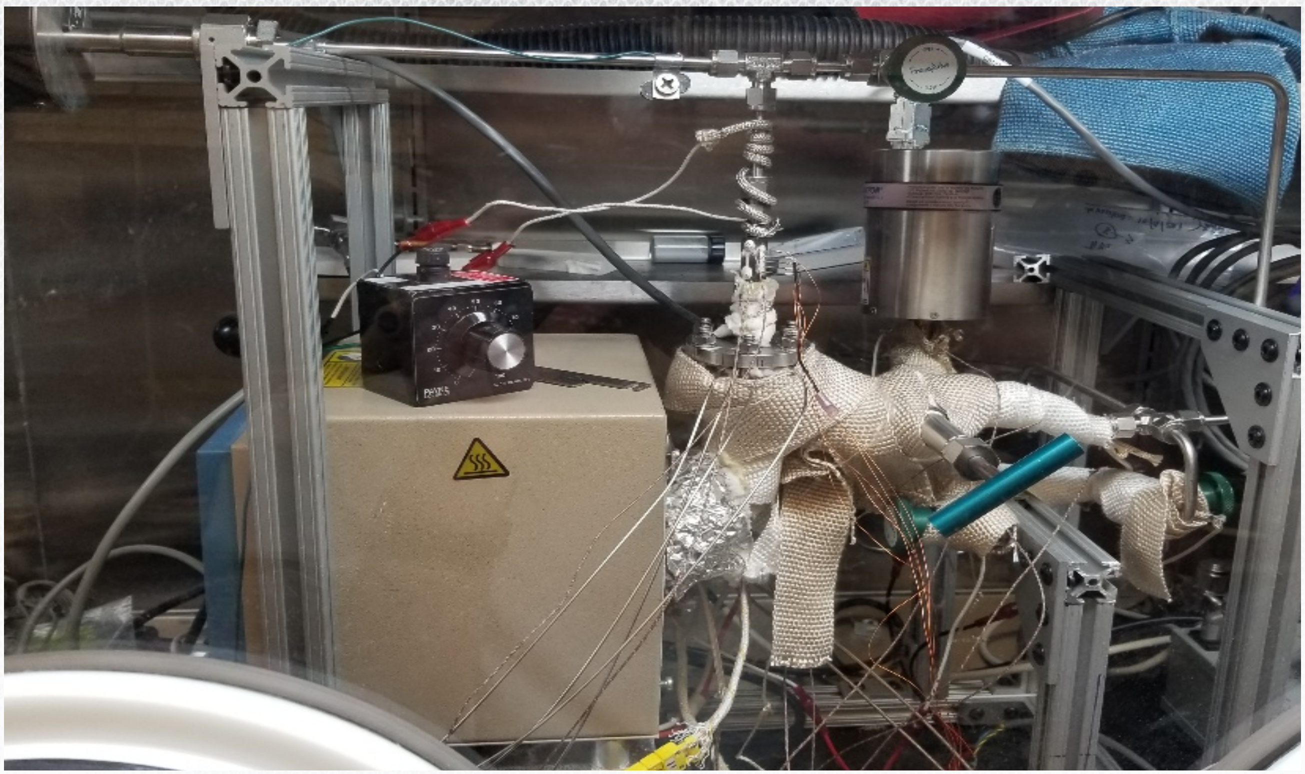
Kelvin Equation at interface $$P(x_i) = P_{sat}(T_i)\exp\left(\frac{P_L}{\rho_l T_i \bar{R}}\right)$$

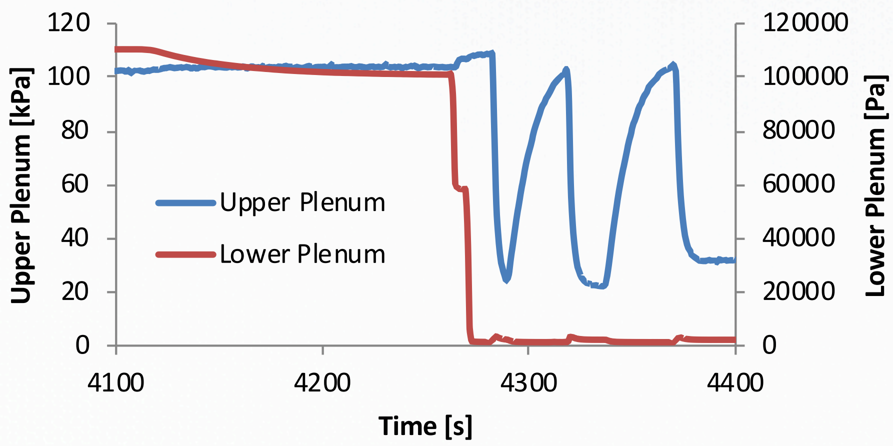
Momentum Conservation for slip flow $$u = -\frac{\kappa_\infty (1 + 8\beta Kn)}{\mu}\frac{dP}{dx}$$

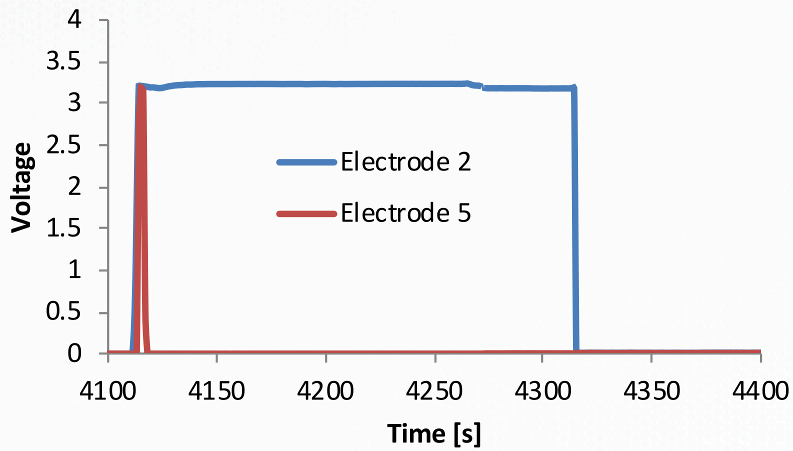




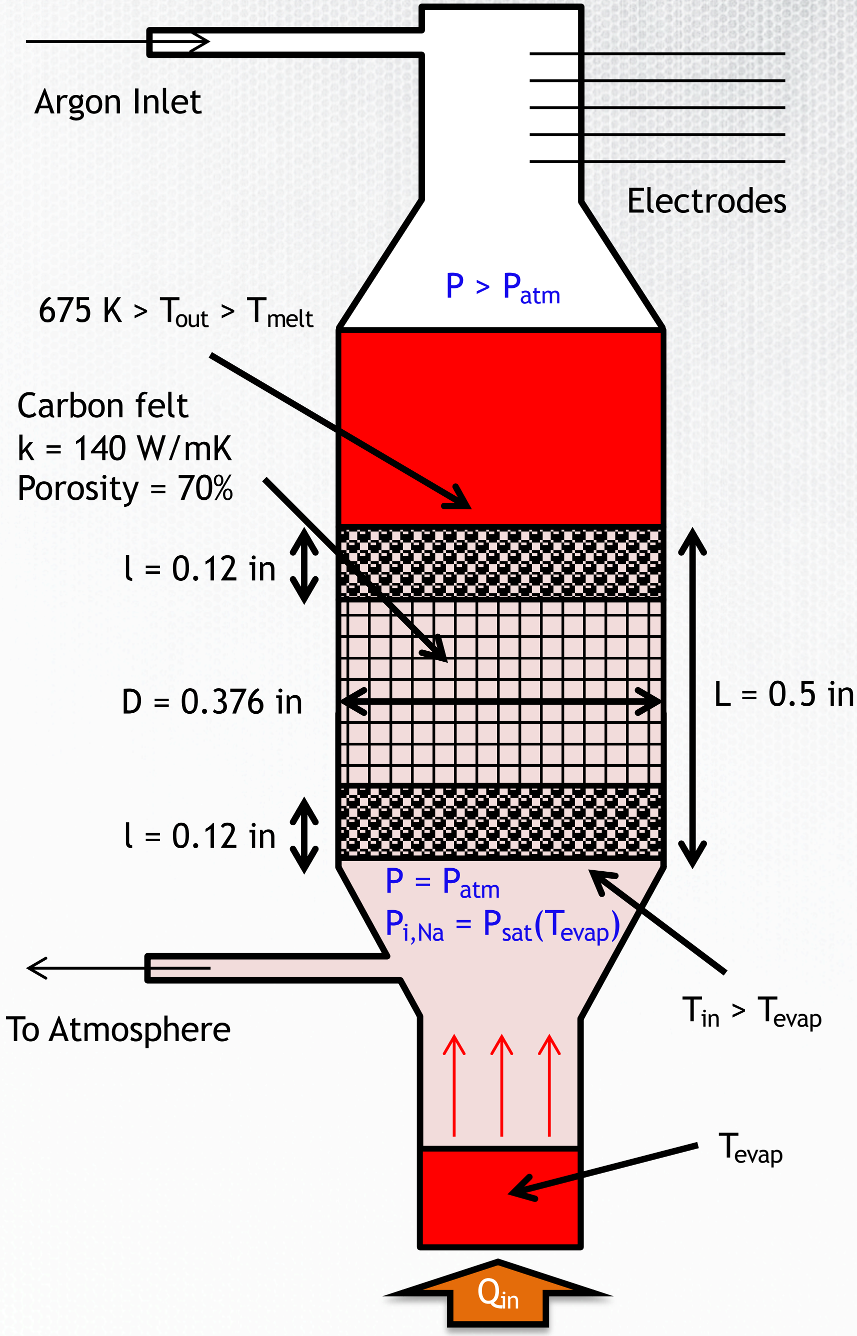
Failed Vacuum Experiment





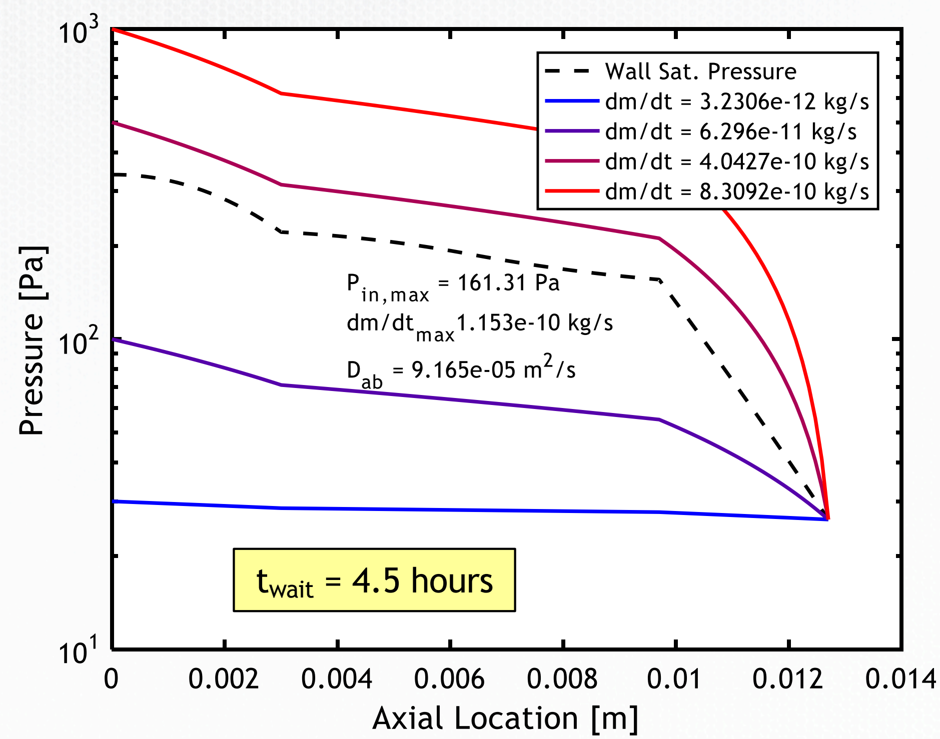


Gauge Pressure Experiment

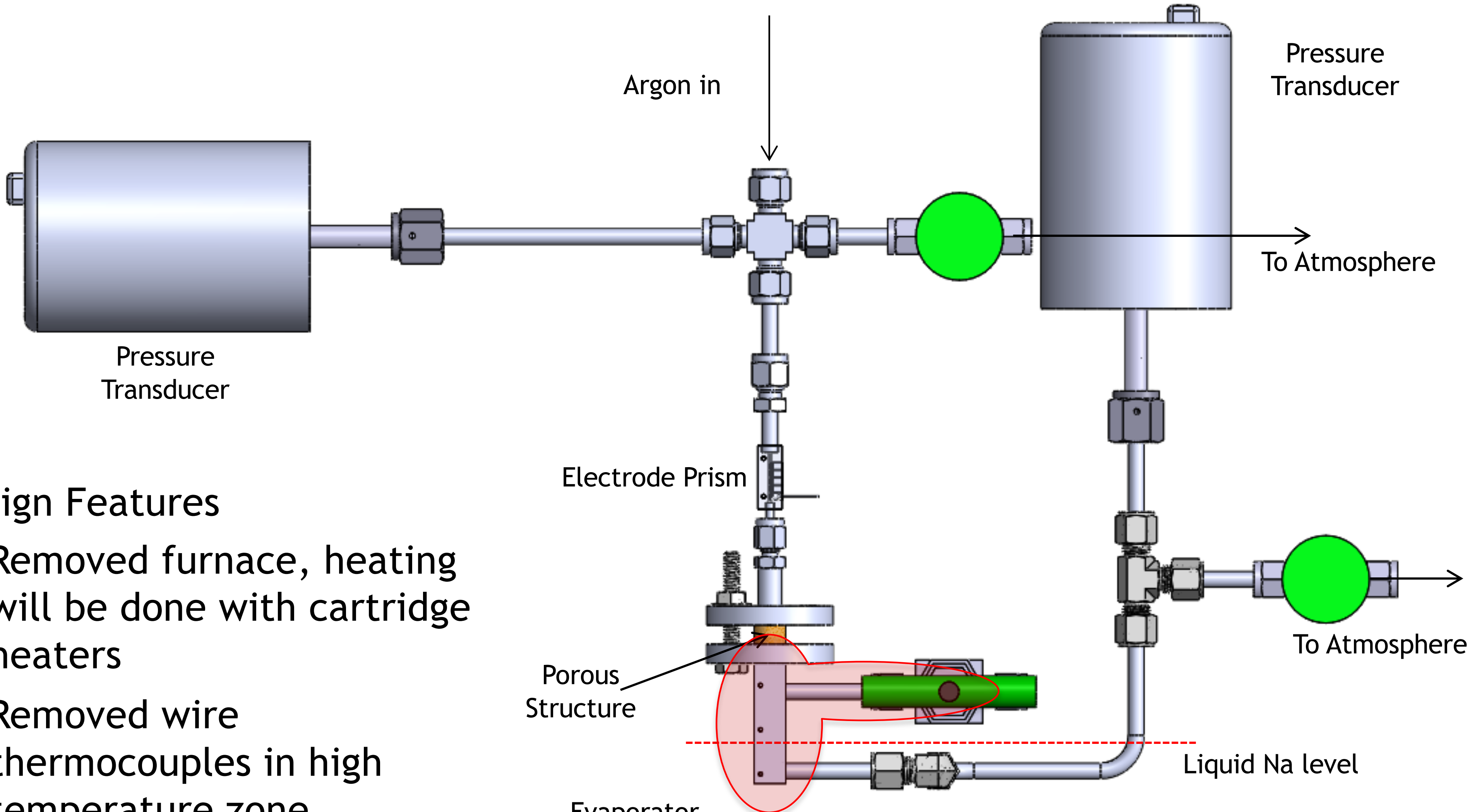


$$u = \frac{\rho_{Na} u_{Na} + \rho_{Ar} u_{Ar}}{\rho} = \omega_{Na} u_{Na}$$

If $\omega_{Na} << 1$
use dilute gas approximation to neglect advection



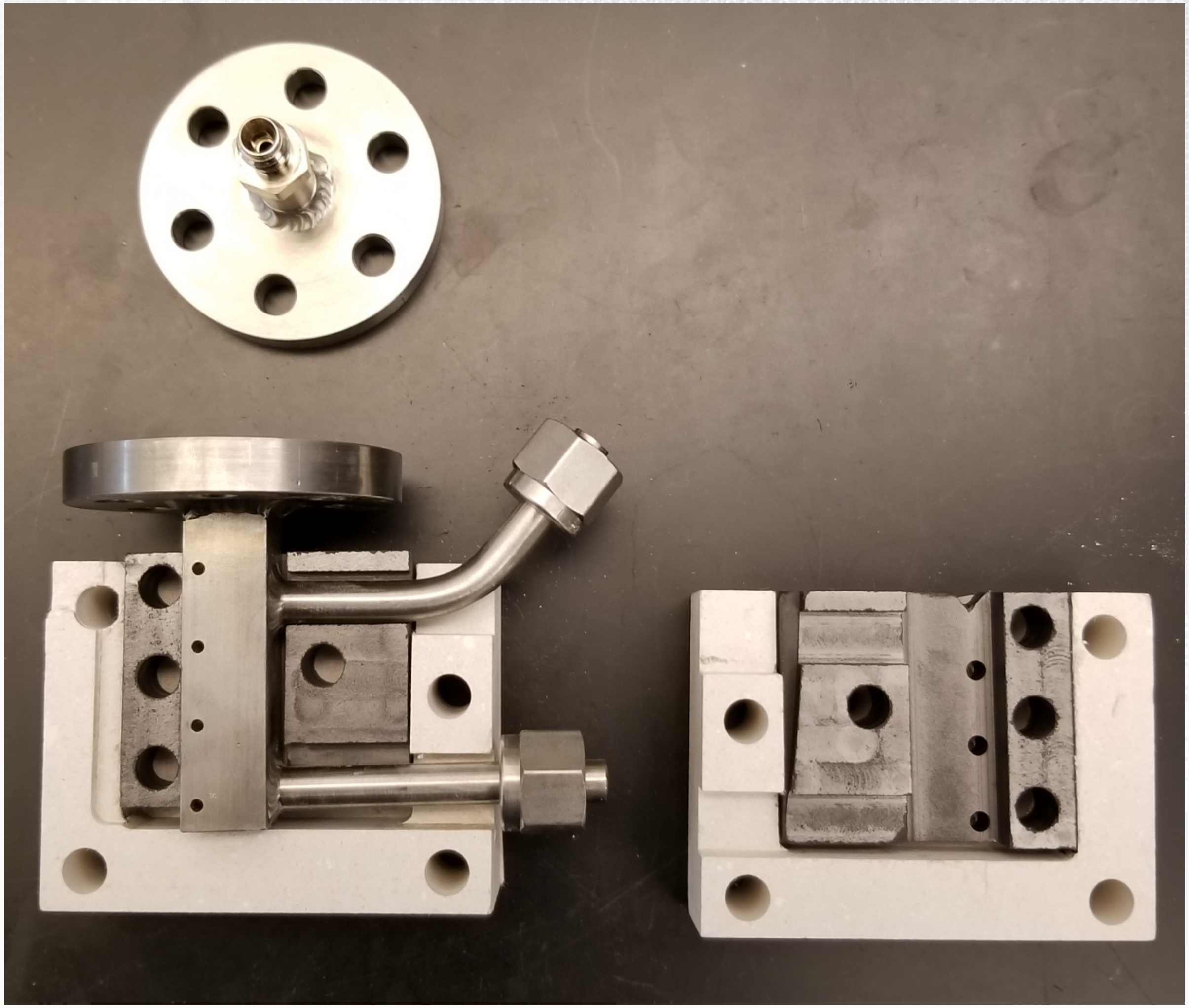
New Experimental Design

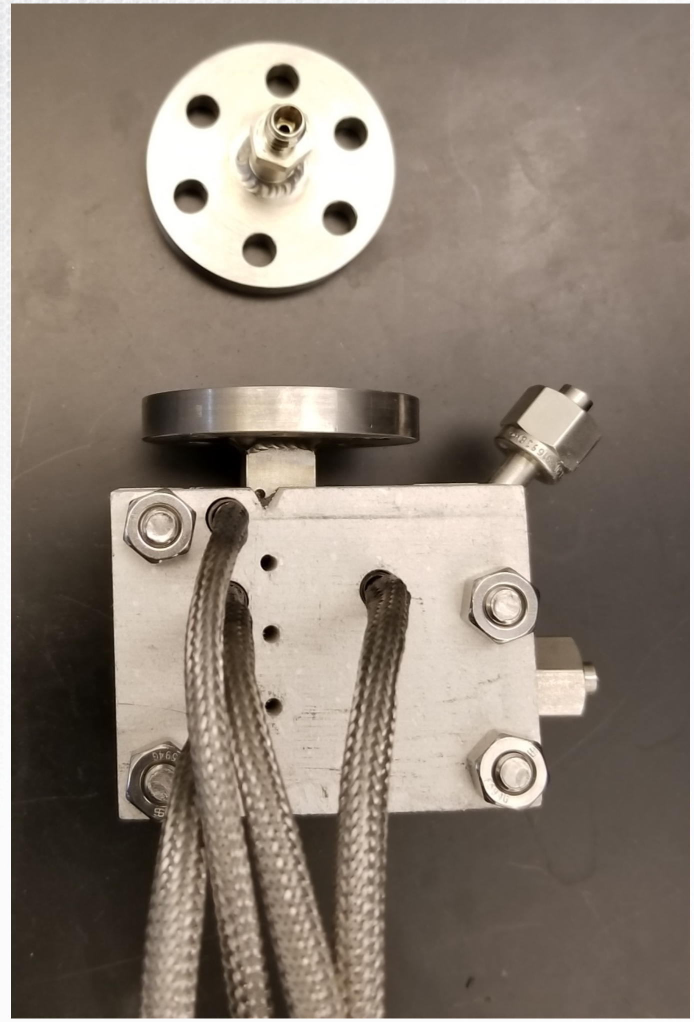


Design Features

- Removed furnace, heating will be done with cartridge heaters
- Removed wire thermocouples in high temperature zone
- Reduced thermal mass of flanges by 36%

New Heater Design





Summary and Future Work

Summary:

- Discussed transport model for combined advection/diffusion
- Introduced the experimental design used to demonstrate sodium pumping
- Described experimental modification

Future Work:

- Finish building new experimental set-up. Gather data
- Validate experiment with conjugate heat transfer Comsol modeling
- Use DGM for modeling purposes
- Run experiment with different porous materials

Acknowledgements

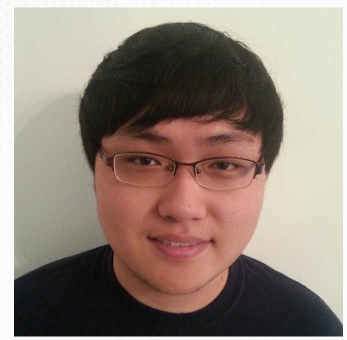
Georgia Institute of Technology

Prof. Shannon Yee
Prof. Andrei Fedorov
Dr. Peter Kottke
Rhitesh Bhatt

Prof. Seung Woo Lee
Dr. Andrey Gunawan
Jong Ha





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