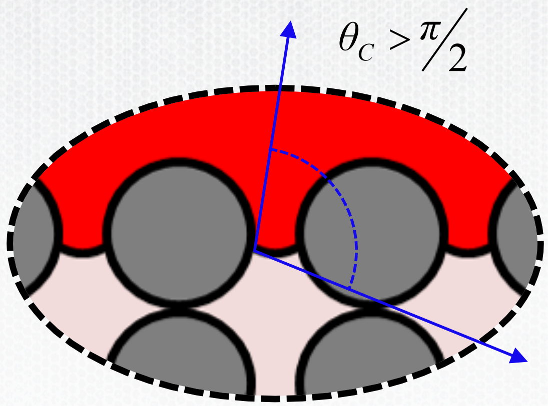
# Sodium Pumping via Condensation within a Non-Wetting Porous Structure

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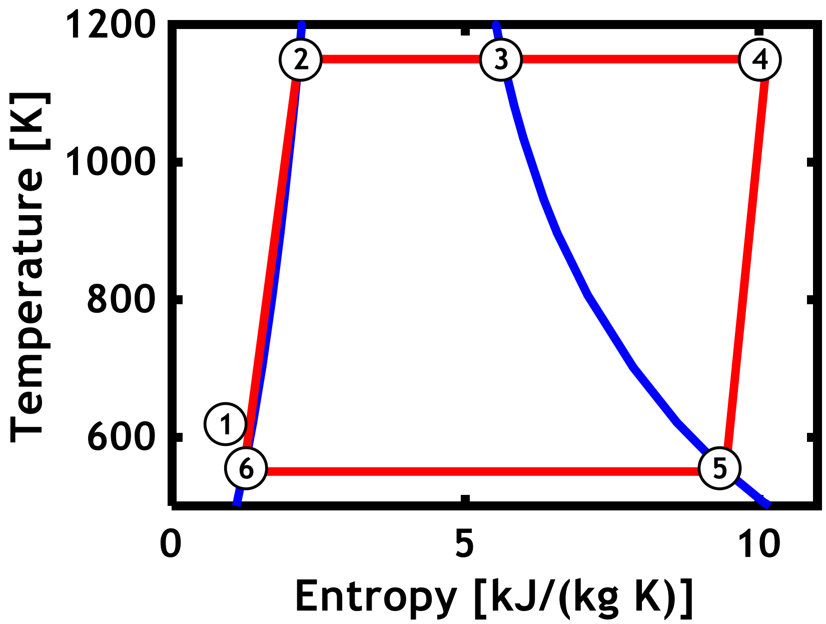
*July 14, 2017*

*Scalable Thermal Energy Engineering Laboratory*
*Woodruff School of Mechanical Engineering*

# Sodium Thermal Electrochemical Converter (Na-TEC)




1-2 : Isobaric Heating

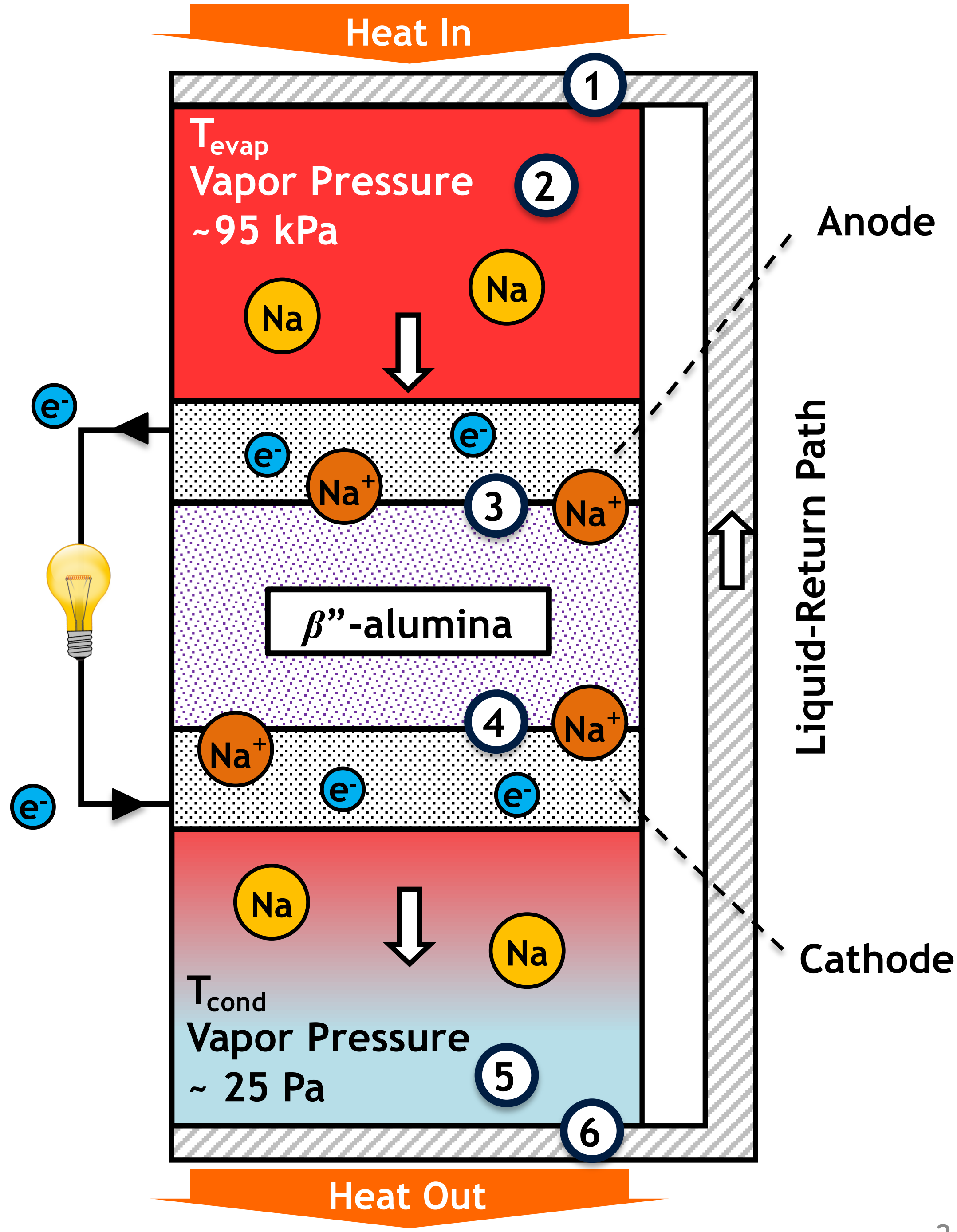
2-3 : Vaporization

3-4 : Isothermal Expansion

4-5 : Isobaric Cooling

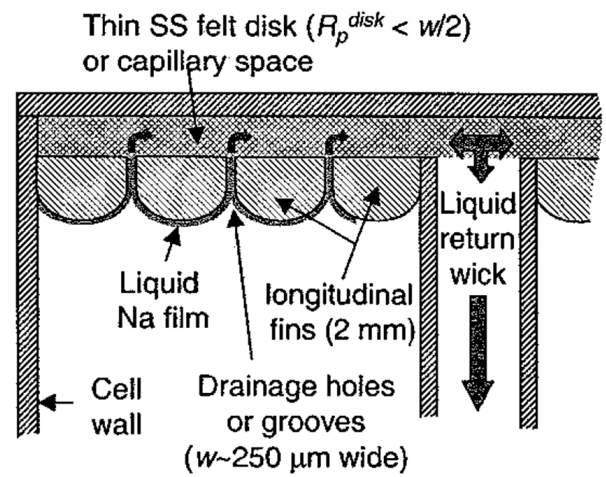
5-6 : Condensation

6-1 : Isentropic Pumping

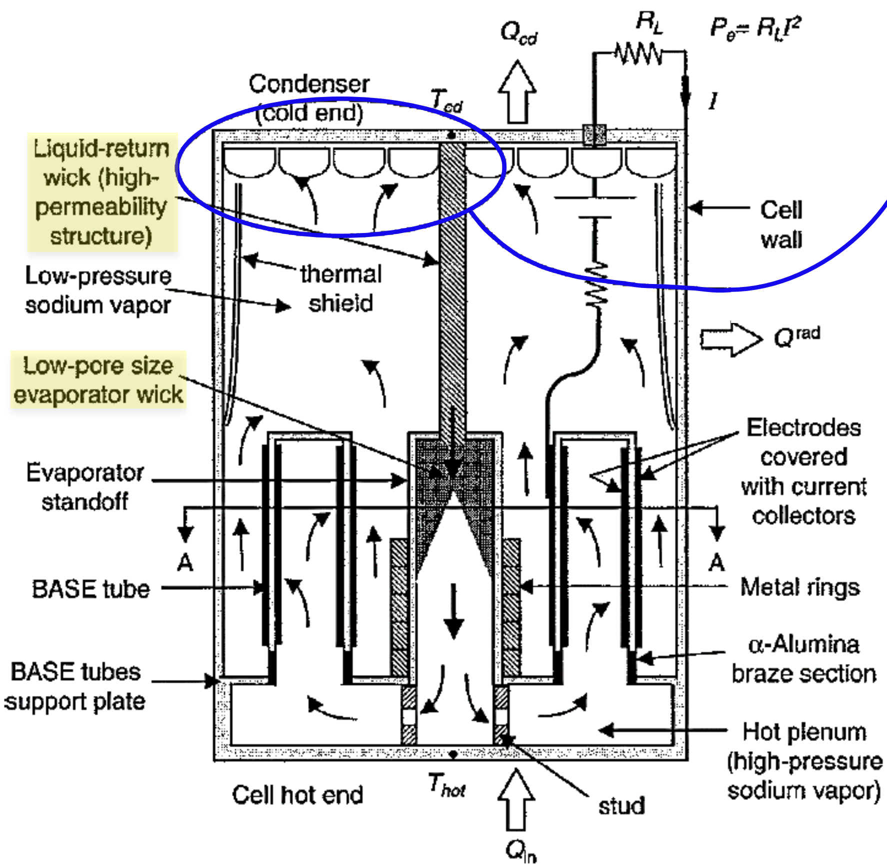


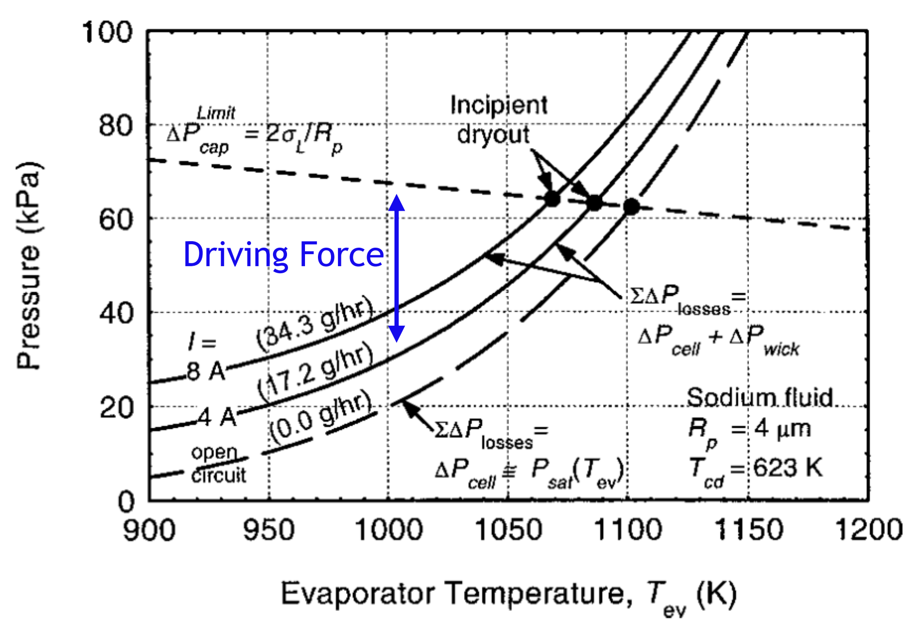
# History of Na-TEC Wick Development

- First wicks were tested in 1980's for microgravity operation
- Competition between efficient liquid transport and capillary driving force



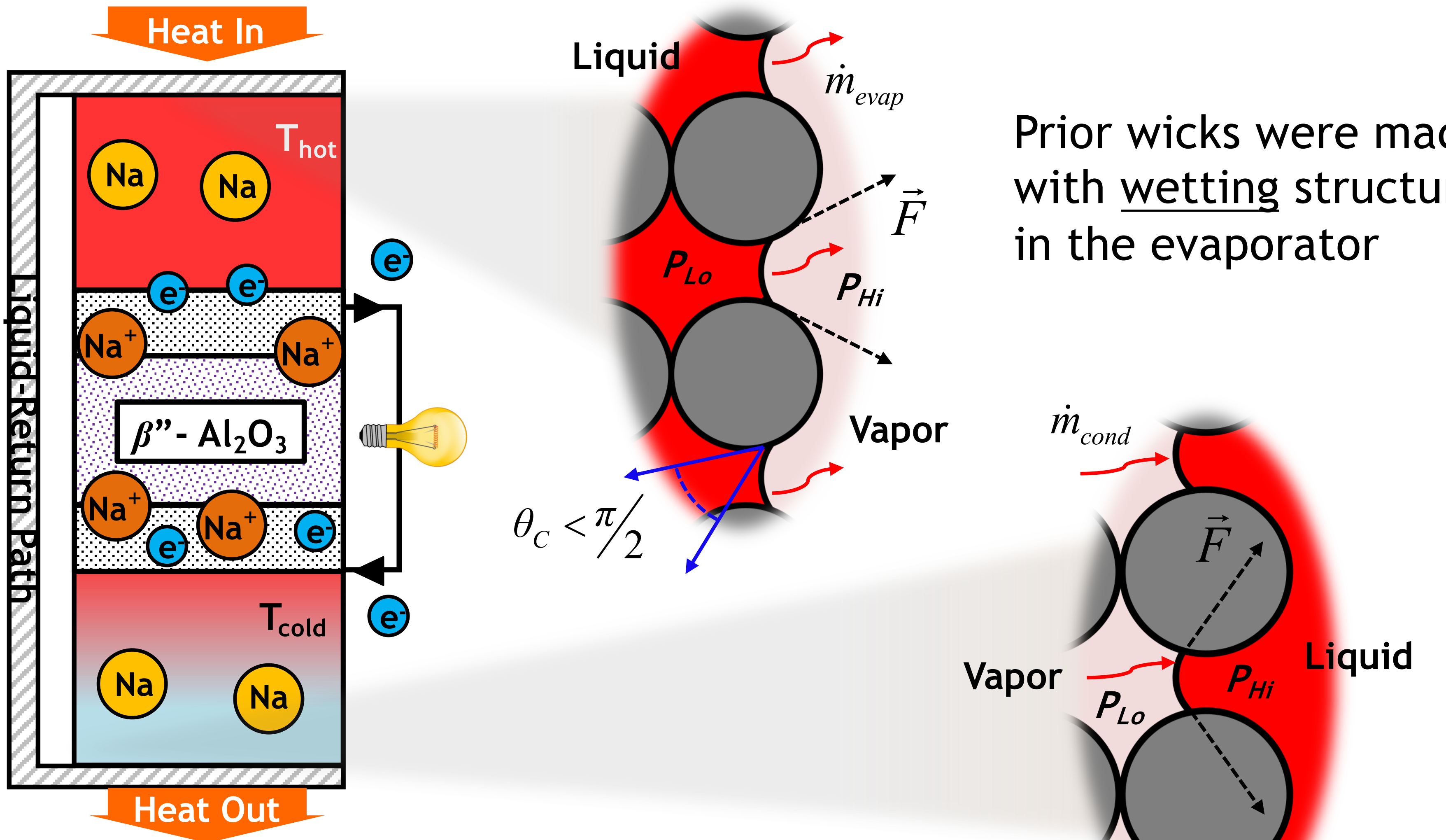
Creare condenser design




Tournier and El-Genk, *Journal of Thermophysics and Heat Transfer, 2002*

# Non-Wetting Capillary Pumping of Liquid Sodium



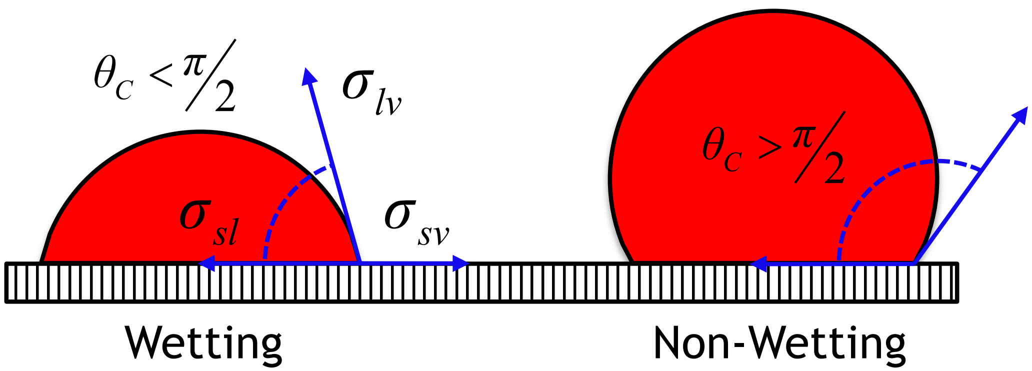

Prior wicks were made with wetting structures in the evaporator

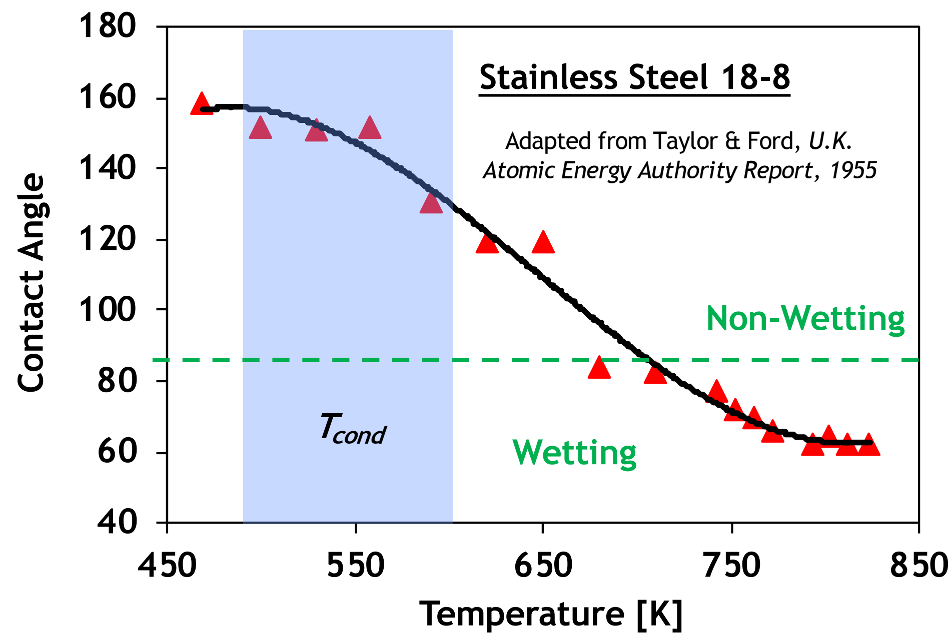
Can a non-wetting porous structure enable low-temperature capillary pumping solutions in the condenser?

# Interfacial Pressure is a Function of Surface Energy, Contact Angle, and Pore Size

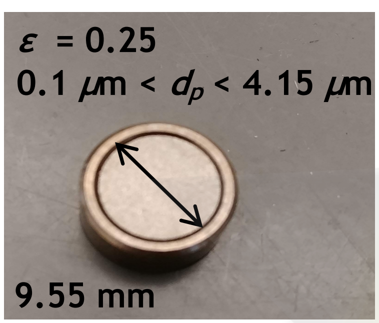
Laplace Pressure $P_i - P_o = \Delta P = 2K_{12}\sigma$

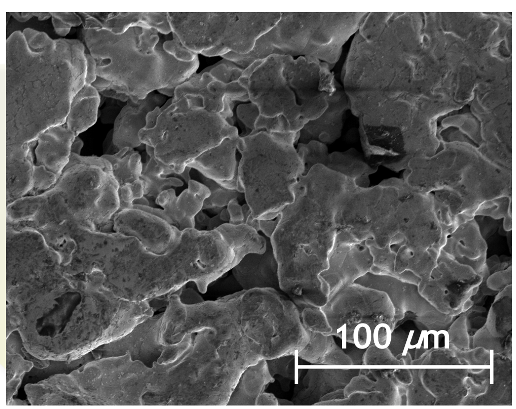
Young-Dupree Equation $\sigma_{sv} = \sigma_{sl} + \sigma_{lv}\cos\theta_C$



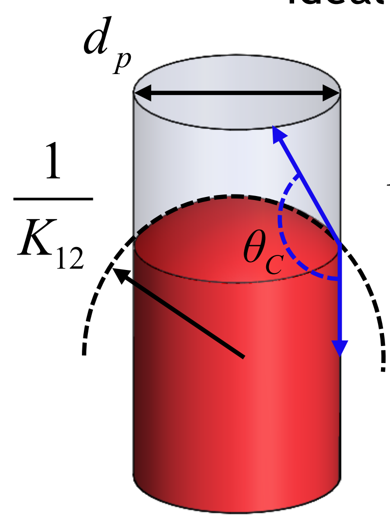




SS 316 porous structure thermally pressed inside cylinder:



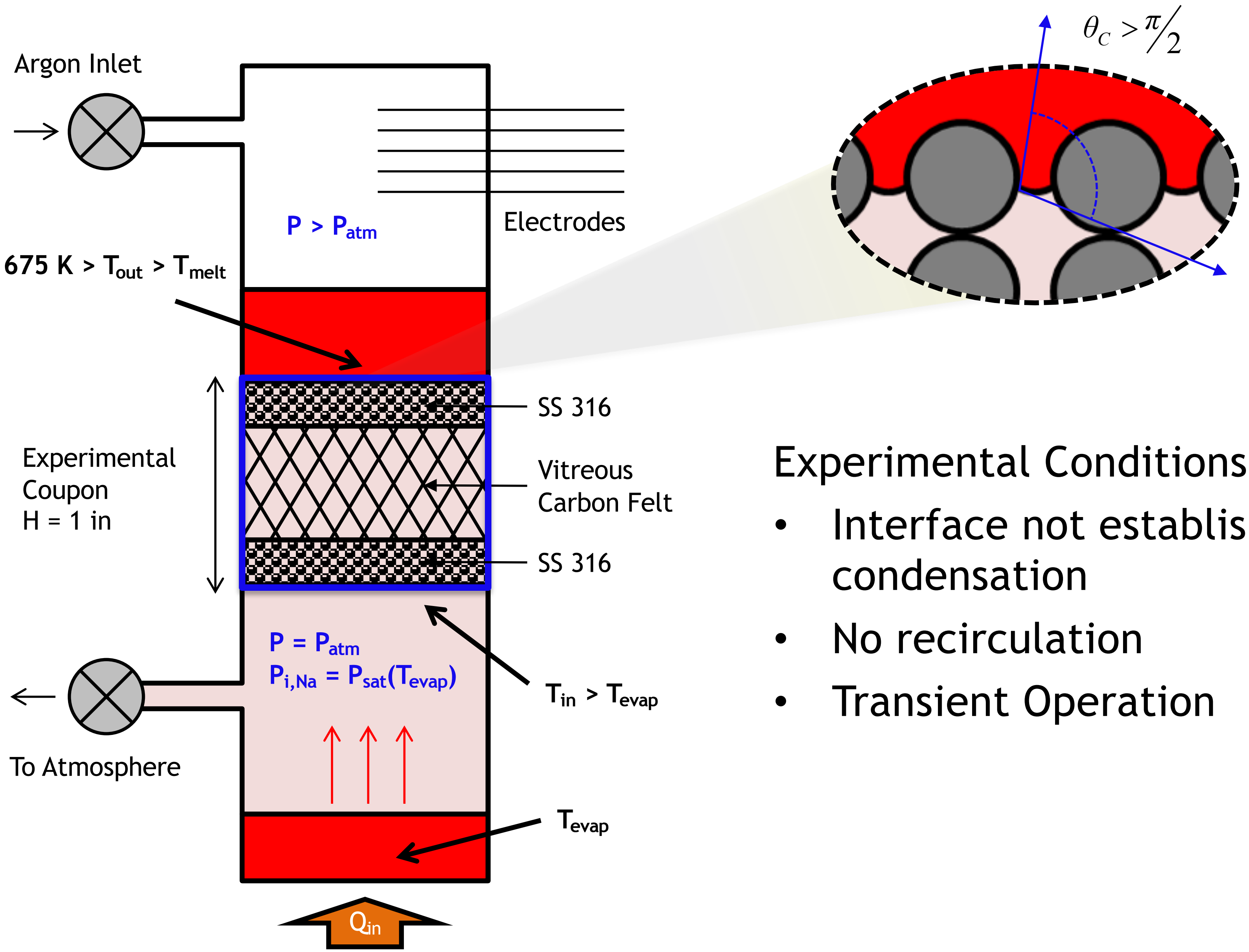




Idealized Cylindrical Pore




$$P_L = \frac{4\sigma_{lv}}{d_p}\cos(\pi - \theta_C)$$

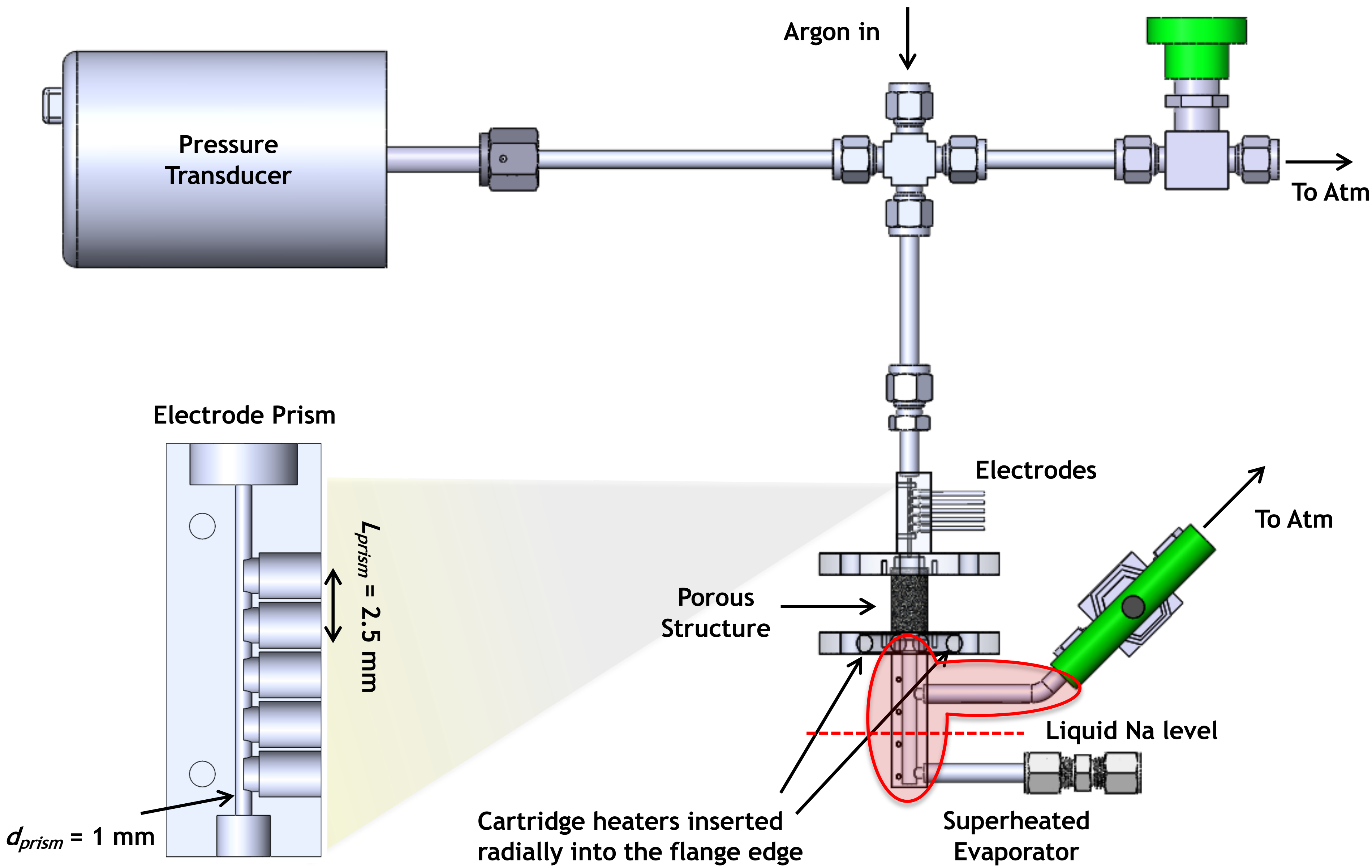
# Sodium vapor diffuses through the porous structure and condenses at the liquid-vapor interface



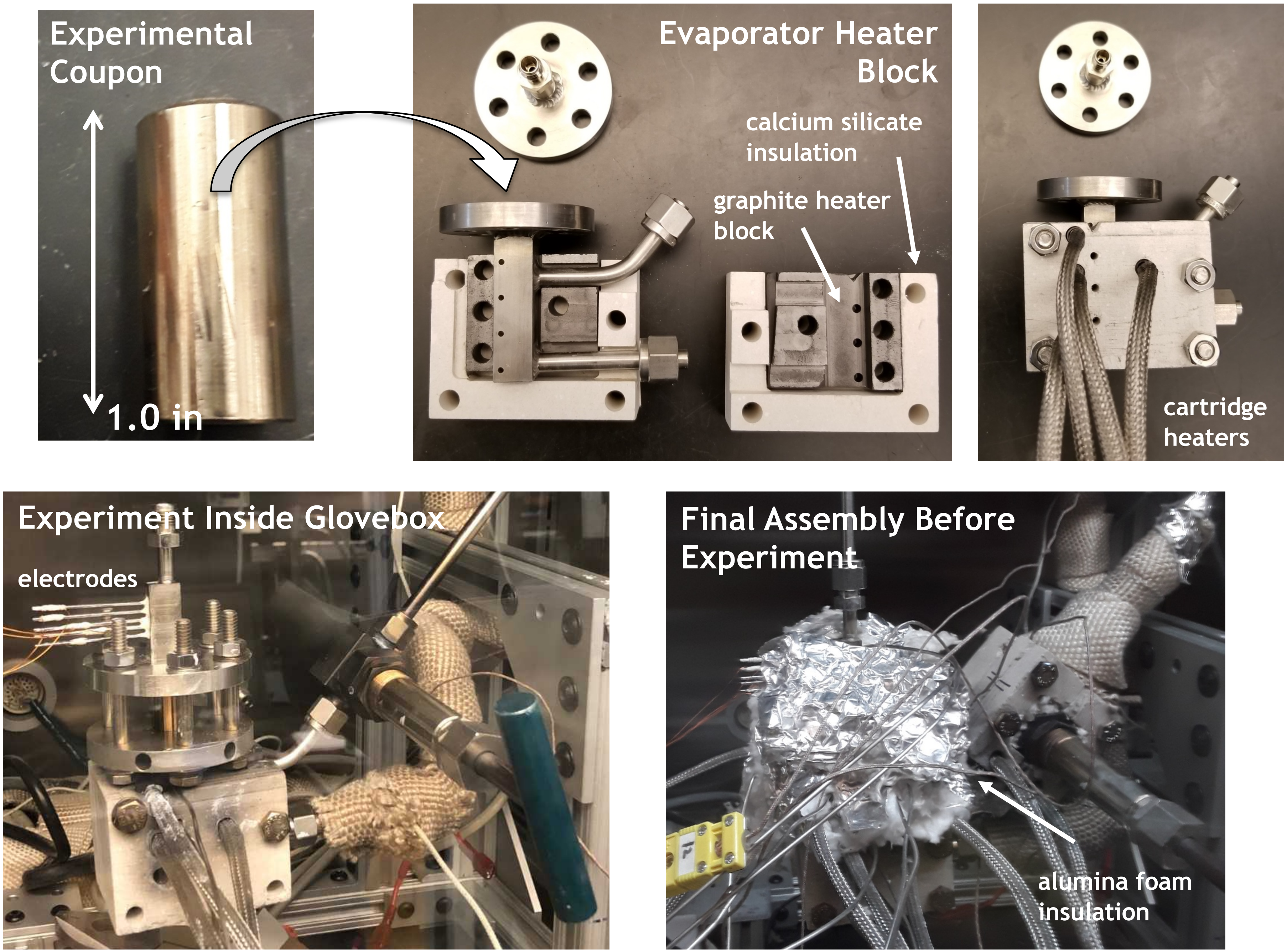

Experimental Conditions:

- Interface not established via condensation
- No recirculation
- Transient Operation

# An electrode prism measures the sodium flowrate at various pressures



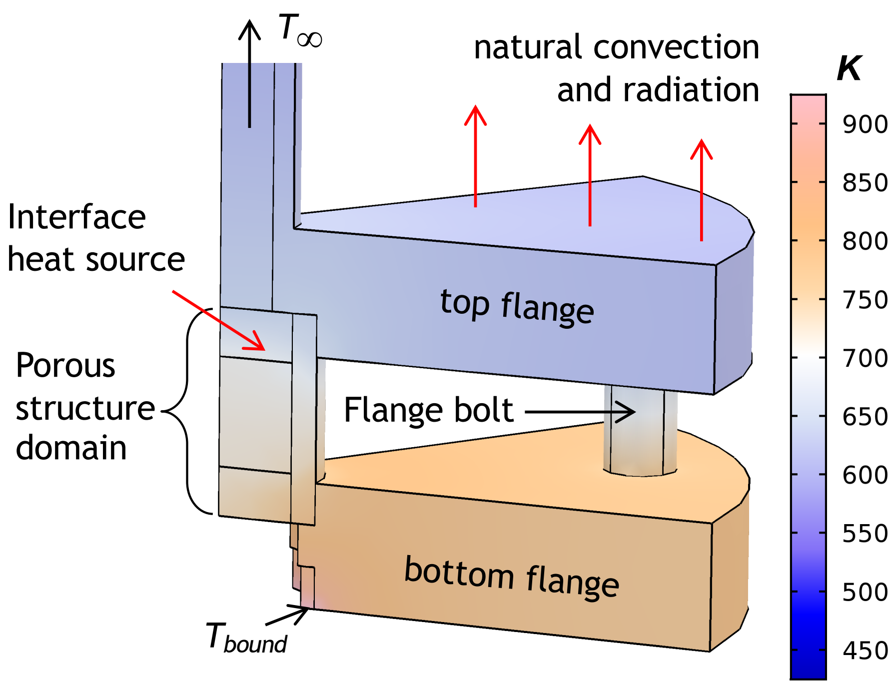
# Physical Experiment Assembly



# A Conduction Model is Used to Predict the Temperature Profile Within the Experimental Coupon

A quasi-axisymmetric 3D COMSOL model approximates the coupon temperature profile:

**1/6 geometry with radiation symmetry**

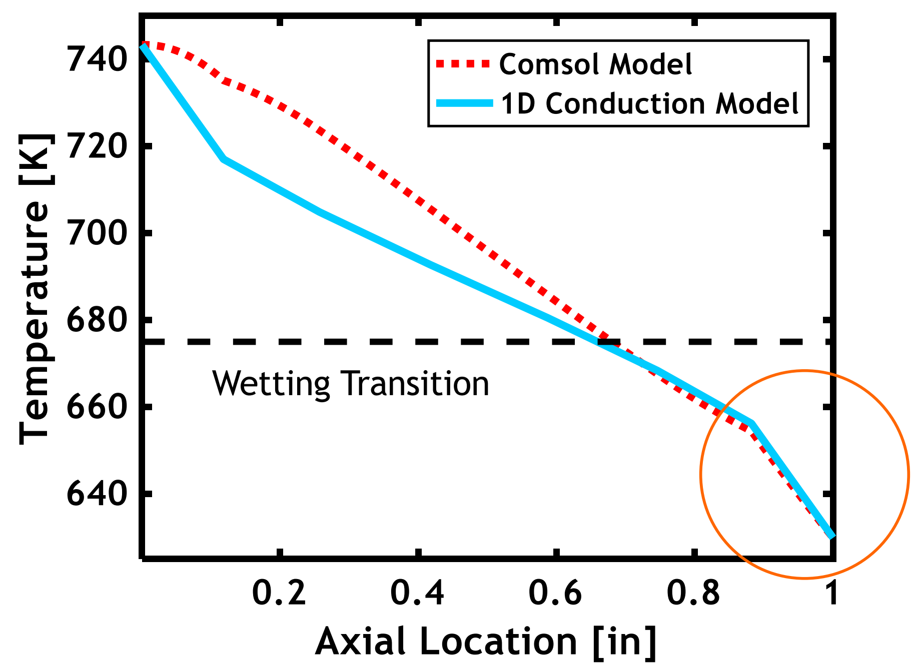



Use a 1D conduction model to estimate the central axial temperature

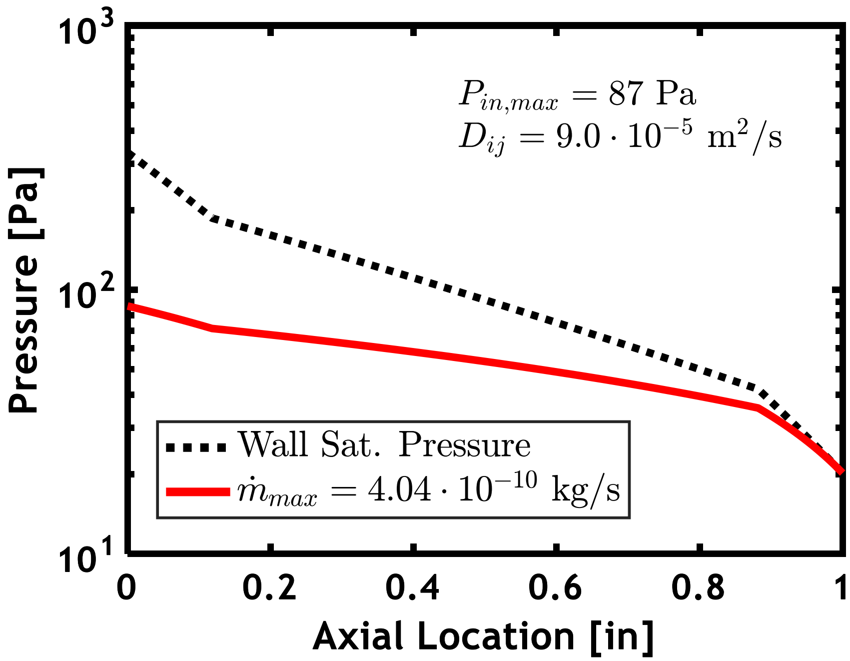
Consider only the experimental coupon with fixed temperature boundaries:

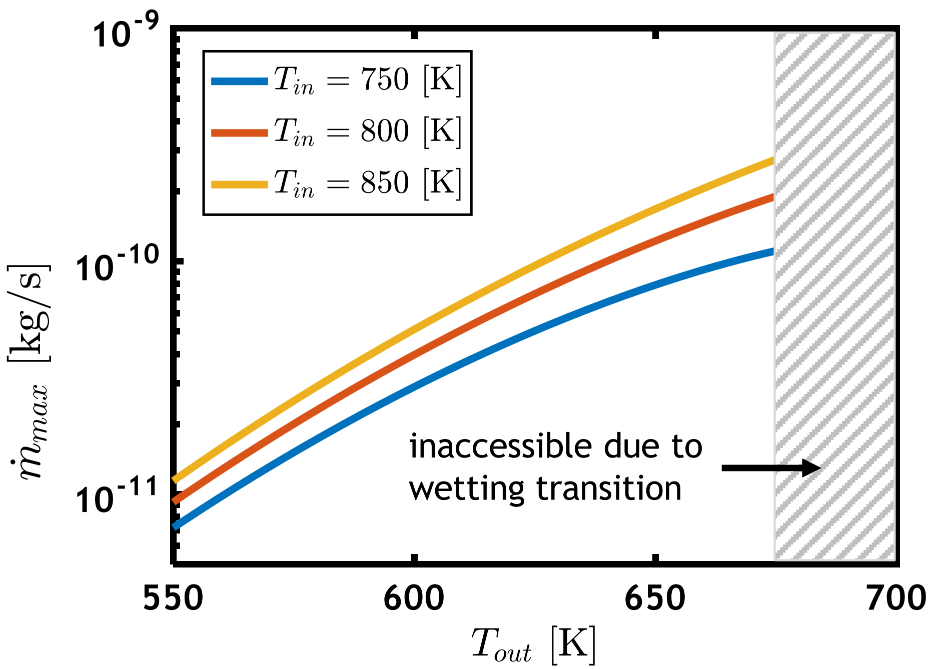
$$k_{eff} = (1-\varepsilon)k_s + \varepsilon k_g$$

$$\begin{cases} k_{eff} \approx 15 \text{ W/m/K, } \varepsilon = 25\%\text{, SS 316} \\ k_{eff} \approx 42 \text{ W/m/K, } \varepsilon = 70\%\text{, Vitreous Carbon} \end{cases}$$



# The Maximum Mass Flowrate is Limited by the Temperature




Quasi-steady 1D model assumptions:

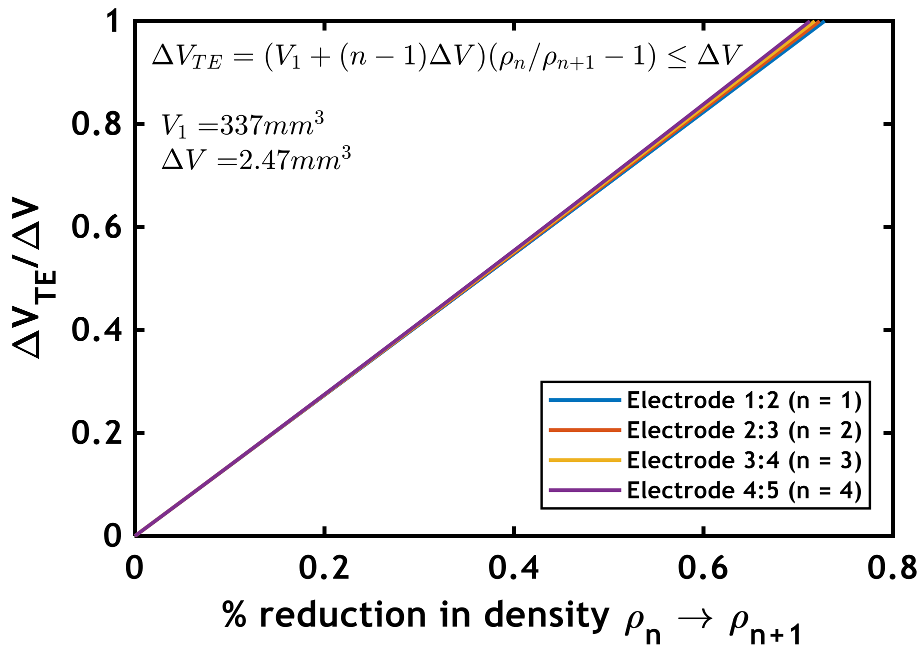
1. Stationary condensation front
2. Infinitesimal two-phase zone
3. Dilute gas approximation $\omega_{Na} \ll 1$
4. Uniform capillary pressure

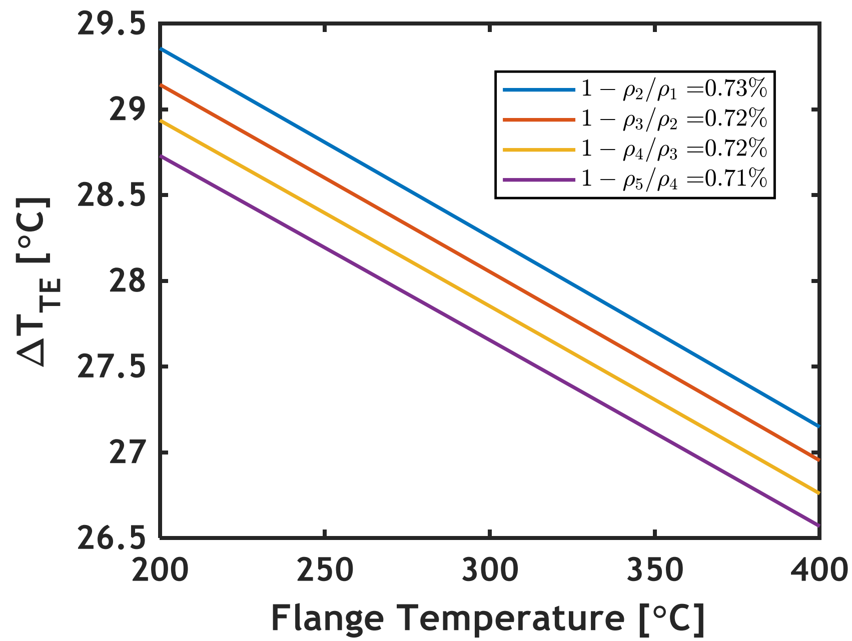
$$\dot{m}_{Na} = A\varepsilon D_{ij,T}\rho_T \frac{d}{dx}\left(\frac{\rho_{Na,T}}{\rho_T}\right)$$

$$\begin{cases} P_{x=0} = P_{sat}\left(T_{evap}\right) \\ P_{x=L} = P_{sat}\left(T_{out}\right)\exp\left(\dfrac{P_L}{\rho_{T_{out}} T_{out} R}\right) \end{cases}$$

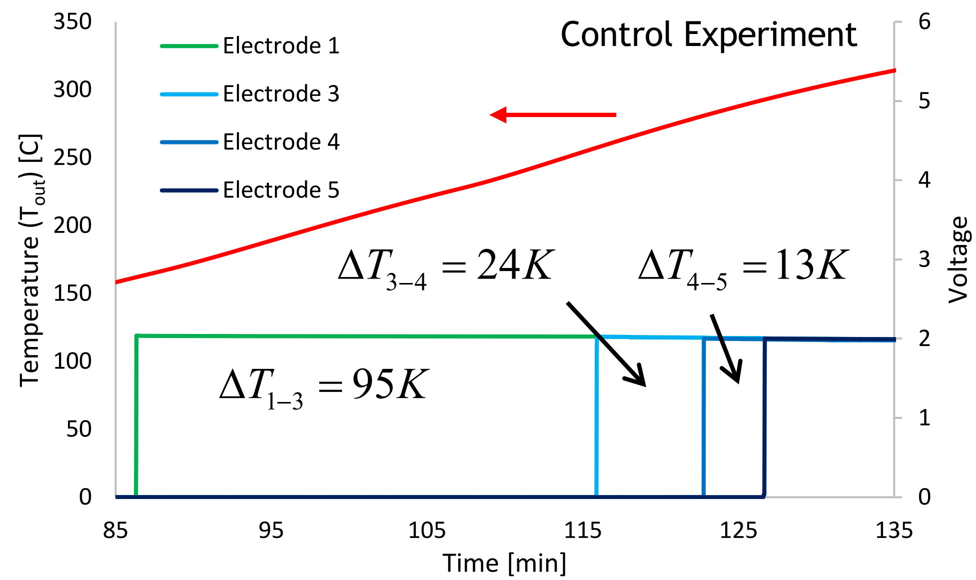
experimental wait time $\quad t_{wait} = \dfrac{L_{prism}\rho_{sat,\bar{T}}}{A_{prism}\dot{m}_{Na}}$

# How to Differentiate Between Liquid Sodium Pumping and Thermal Expansion

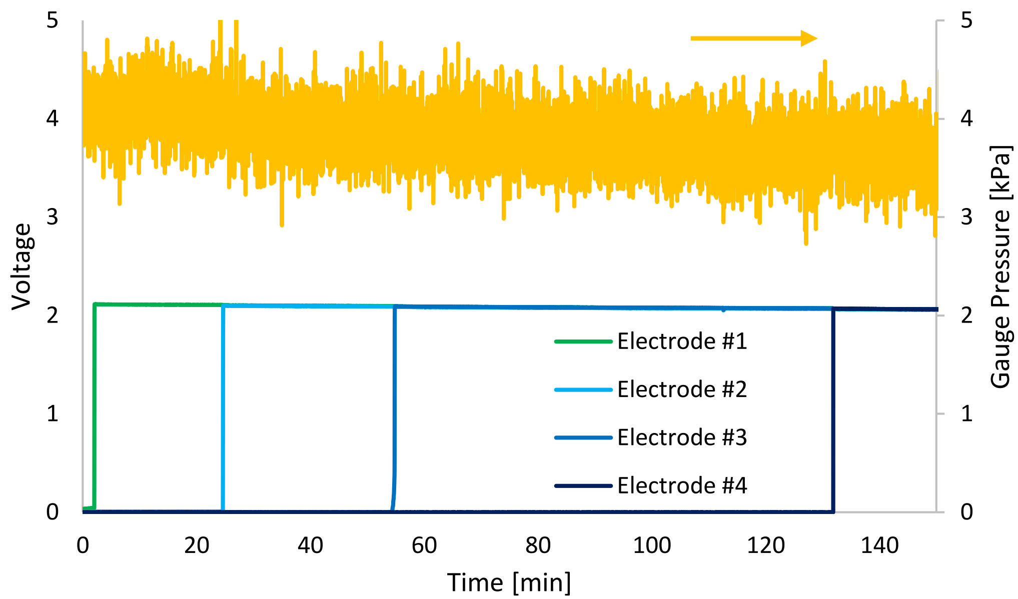


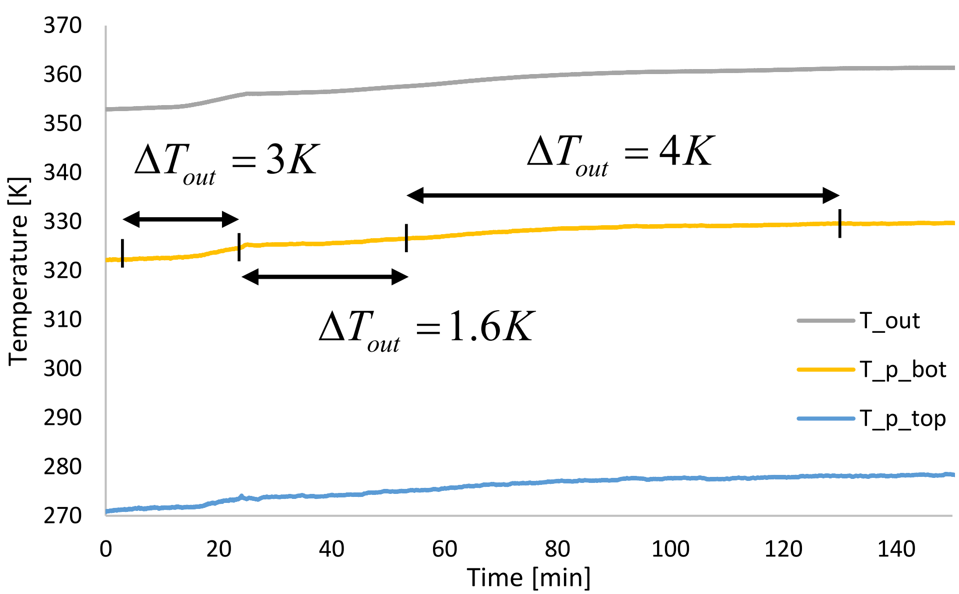




- Thermal expansion requires a density reduction of ~ 0.7%
- This requires a temperature increase of ~ 30K
- Control Experiment shows temperature change > 13K



# Summary of Experimental Results - 6/6/19




- Liquid pumping was achieved at a *ΔP* of ~3.8 kPa
- Electrode activation is not accounted for by thermal expansion

$$T_{in} = 492^{\circ}C$$

$$T_{evap} = 449^{\circ}C$$

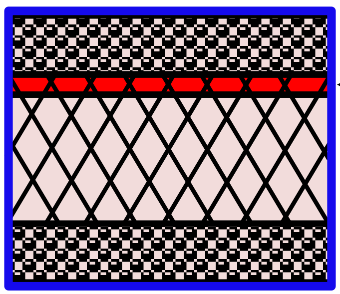
$$\dot{m}_{meas} = 3.0\times10^{-10} kg/s$$

$$\dot{m}_{pred} = 5.9\times10^{-11} kg/s$$

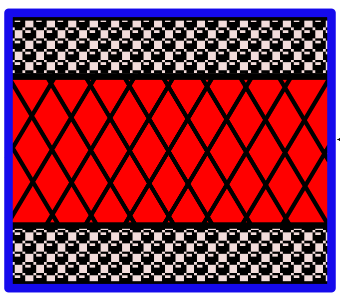
Why is observed mass flowrate much faster than predicted?

# Several Experimental Conditions Require Deeper Exploration

Post-processing of experimental coupon:



6/14/19 Run
Thin layer of sodium observed after opening the coupon

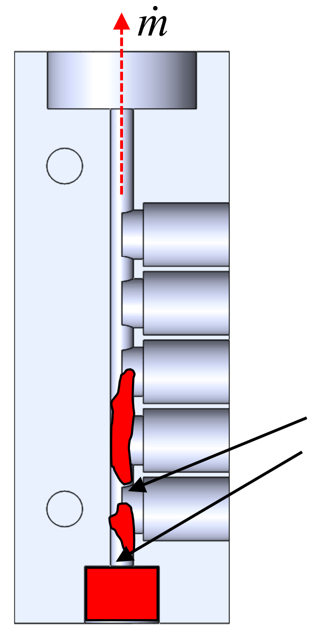


Unknown Run
Entire carbon felt area covered with sodium

a) Is condensation occurring during cooling?

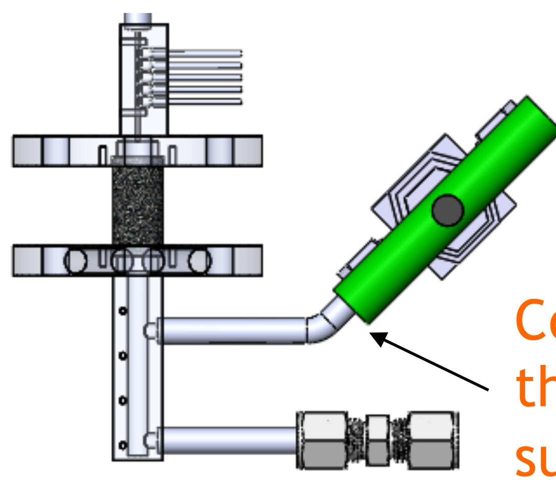
b) Is diffusion rate exceeding pumping rate?

c) Is condensation flooding the pores during heating?




Argon may be trapped within the flow path during sodium melting

Bubble expansion affects the flowrate calculation



Condensation within the relief valve, suppresses pumping capacity