Oregon State University

OREGON STATE UNIVERSITY
CBEE

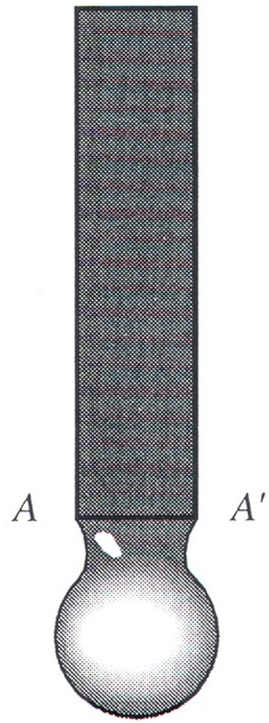
CHE 331
Transport Phenomena I

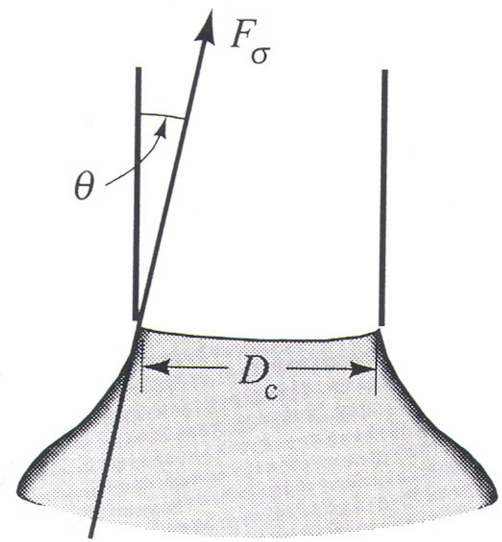
Dr. Goran Jovanovic

Surface Tension Forces II

Please turn-off cell phones
Please wear you mask!!

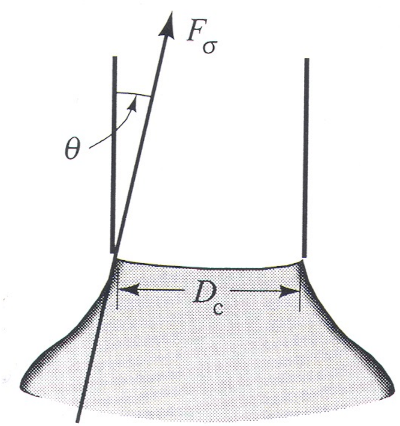
Formation of Droplets





Based on a common experience, we know that as the drop grows, its weight will overcome the force of surface tension that holds the drop to the capillary tip, and the drop will fall off.

Oregon State University



The contact line of the liquid with the capillary is a circle of diameter D_c, and thus the contact line has a length πD_c. The surface in the vicinity of the contact line is not necessarily vertical. The surface tension force in the vertical *Z* direction is:

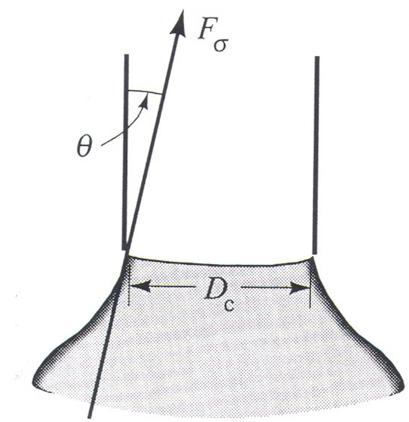
$$F_\sigma \cos(\theta) = \sigma \pi D_c \cos(\theta)$$

If the drop is static, then the restraining-*Surface Tension* force must just balance the weight of the drop;

$$\sigma \pi D_c \cos(\theta) = \rho g_z V$$

We now want to determine the size of the droplet that will detach off the capillary. This will be the maximum size of the droplet.

The simplest speculation is that as droplet gets heavier the angle approaches $\theta = 0$. Therefore,



$$\sigma \pi D_c \cancelto{1}{\cos(\theta)} = \rho g_z V_{\max}$$

$$\pi \sigma D_c = \rho g_z \frac{\pi D_d^3}{6}$$

$$D_d = \left(\frac{6 \sigma D_c}{\rho g_z} \right)^{\frac{1}{3}} \quad \Leftrightarrow \quad \frac{D_d}{D_c} = \left(\frac{6\sigma}{D_c^2 \rho g_z} \right)^{\frac{1}{3}}$$

If we define Bond Number as:

$$\boxed{\mathrm{Bo} = \frac{\rho g_z D_c^2}{\sigma}} \quad \textit{than} \quad \boxed{\frac{D_d}{D_c} = \left(\frac{6}{\mathrm{Bo}} \right)^{\frac{1}{3}} = 1.82 \cdot (\mathrm{Bo})^{-1/3}}$$

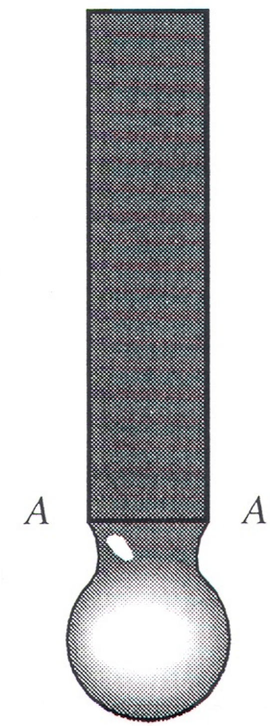
$$\frac{D_d}{D_c} = 1.82 \cdot (\text{Bo})^{-1/3} \quad \Rightarrow \quad \left(\frac{D_d}{D_c}\right)(\text{Bo})^{1/3} = 1.82$$

If this expression is correct, we should find that the right-hand side is independent of the volumetric flow rate:

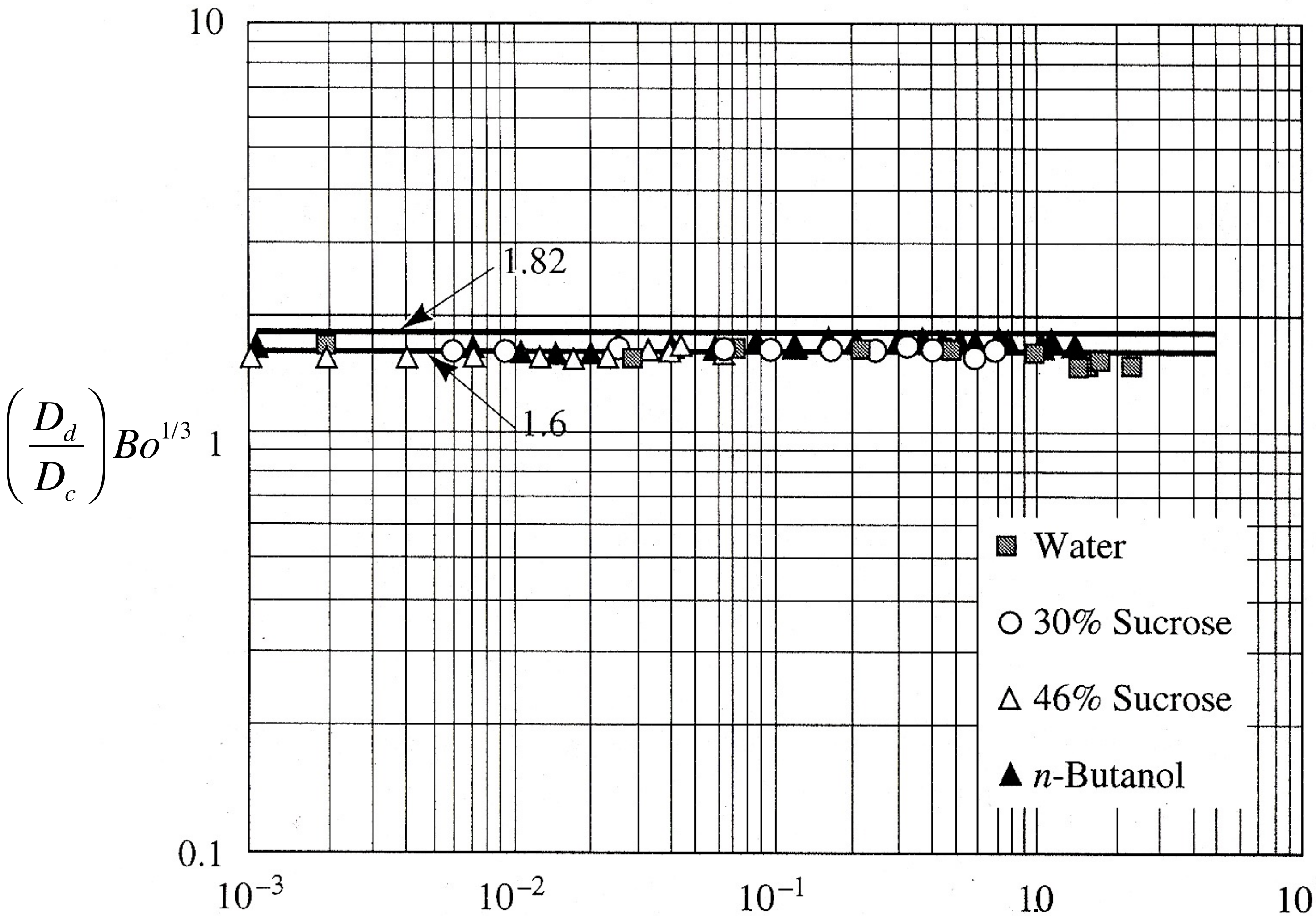
$$\left(\frac{D_d}{D_c}\right)(\text{Bo})^{1/3} \neq f(Q) \quad where \quad Q\left[\frac{m^3}{s}\right]$$

From experimental measurements we can determine that:

$$\left(\frac{D_d}{D_c}\right)(\text{Bo})^{1/3} \approx 1.6$$



Dimensionless droplet size for several liquids, as a function of Weber number.



$$We = \frac{\rho\left(\frac{4Q}{\pi D_{ci}^2}\right)^2 D_{co}}{\sigma}$$

Surface Tension by the "Drop Weight" Method

Water at 20 [°C] drips very slowly from a capillary, and 20 droplets are collected and weighed. The total mass of collected droplets is 0.448 [g]. (we may use 'cgs' system of units in examples involving surface tension phenomena).

Close observation indicates that the drops wet the capillary face and are in contact with the outside diameter of the capillary, $D_c = 0.133$ [cm].
Determine the surface tension of water from the above, experimentally obtained information.

To find the drop diameter:

$$\frac{\pi \rho D_d^3}{6} = \frac{mass}{drop} = \frac{0.448[g]}{20[drops]} = 0.0224\left[\frac{g}{drop}\right] \qquad \rho_{H_2O} = 1\left[\frac{g}{cm^3}\right]$$

Oregon State University

$$D_d = \left(\frac{0.0224 \cdot 6}{\pi \rho}\right)^{1/3} = 0.35[cm]$$

$$\boxed{\mathrm{Bo} = \frac{\rho g_z D_c^2}{\sigma}}$$

$$\left(\frac{D_d}{D_c}\right)(\mathrm{Bo})^{1/3} \approx 1.6 \quad \Rightarrow \quad \sigma = 0.244 \frac{\rho g\left(D_d^3\right)}{D_c}$$

$$\sigma = 0.244 \frac{1 \cdot 981 \cdot \left(0.35^3\right)}{0.133} = 77\left[\frac{dyn}{cm}\right] = 0.077\left[\frac{N}{m}\right]$$

Oregon State University

Design of a Drop Dispenser

Pharmaceuticals are often dispensed in the form of droplets; therefore, we require a dispenser that will generate droplets of the desired size. Consider the following requirements in the design of the drop dispenser:

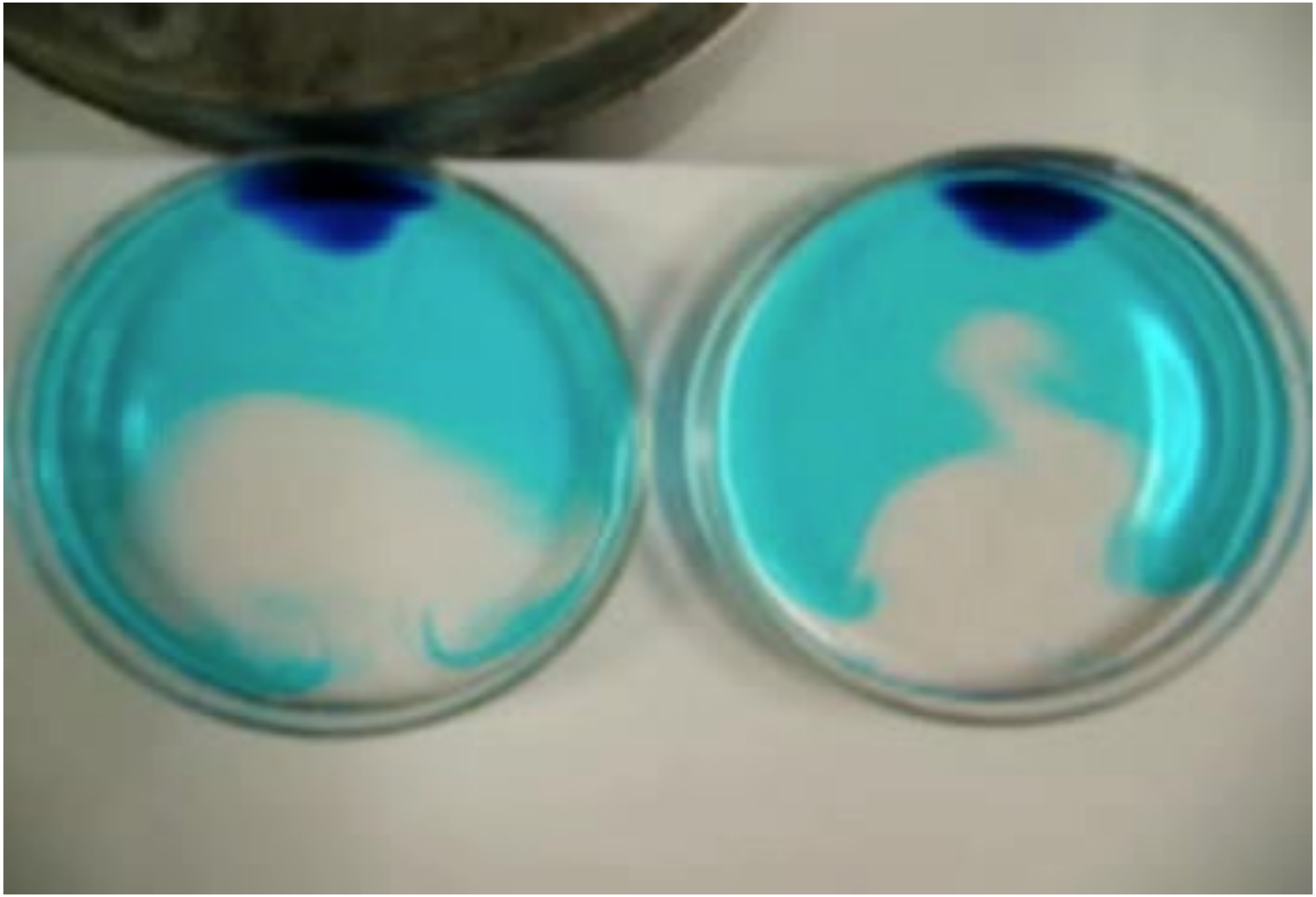
Each drop is to have a volume V_{drop} = 0.014 [cm^3]

Drops are to be produced in air at a frequency of 1 drop every 2.5 [s].

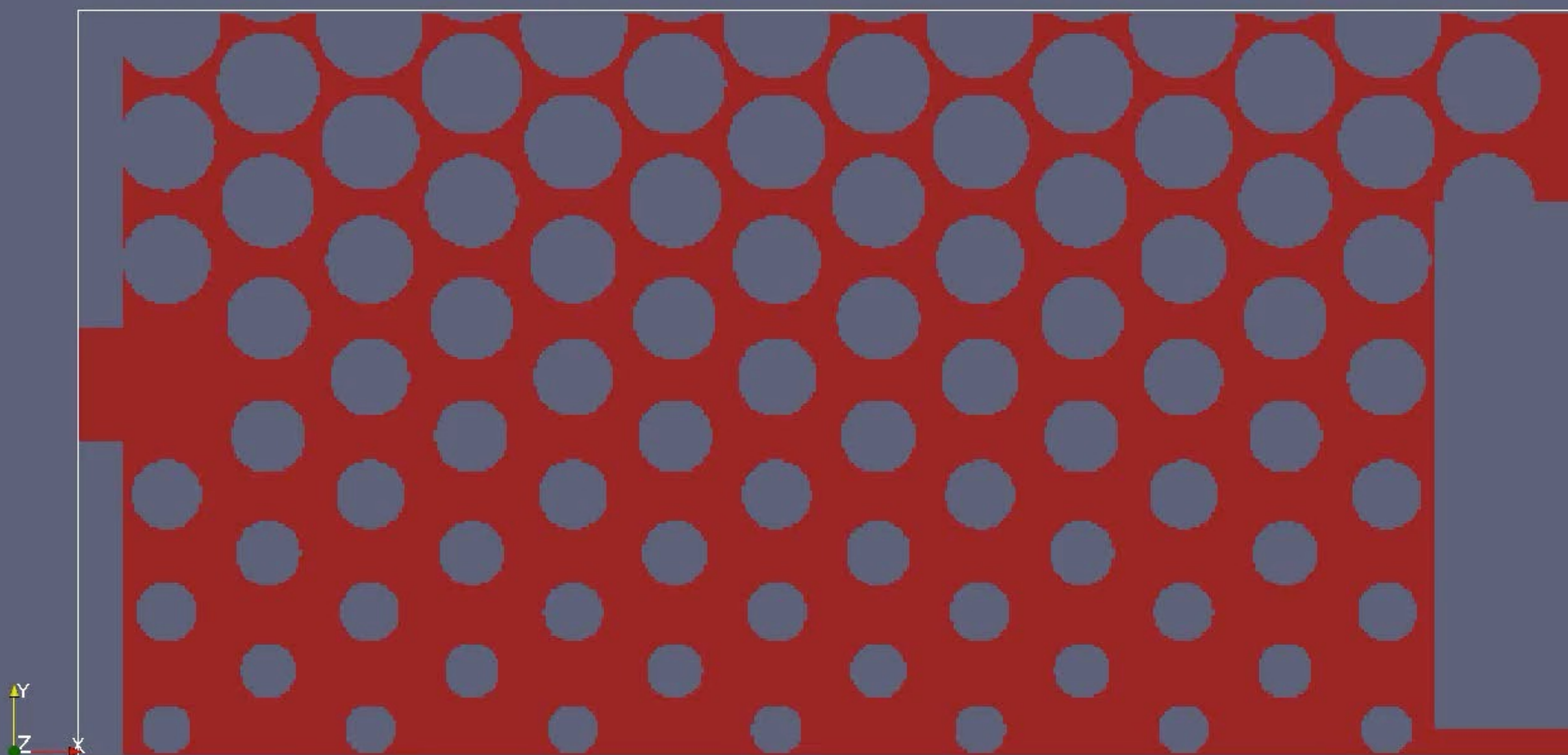
The liquid has a viscosity of twice that of water.
The liquid has a surface tension, with respect to air, of 45 [dyn/cm]

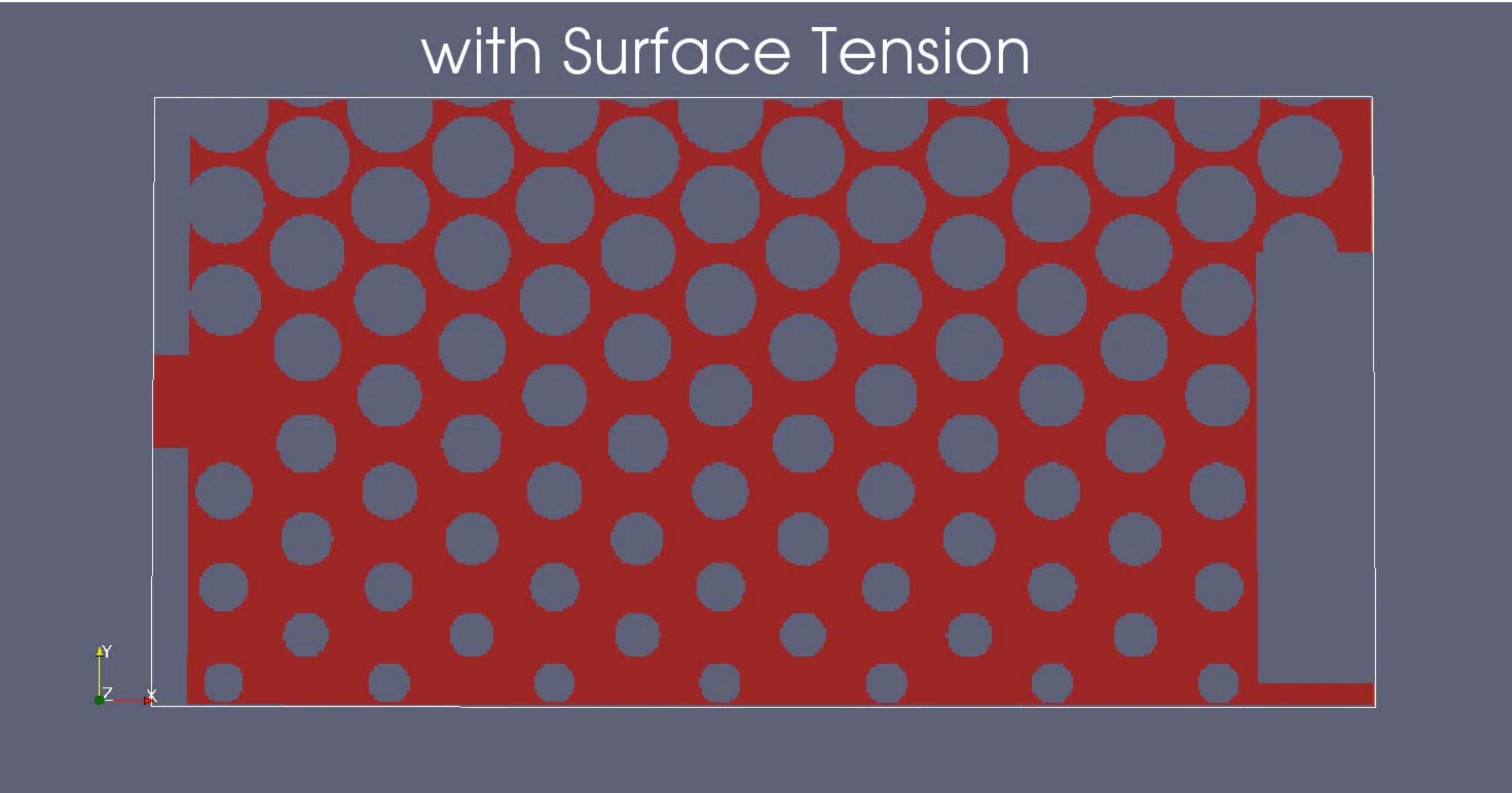
Determine the diameter of the capillary, D_c [cm], and the flow rate of the liquid Q [cm^3/s].

Oregon State University

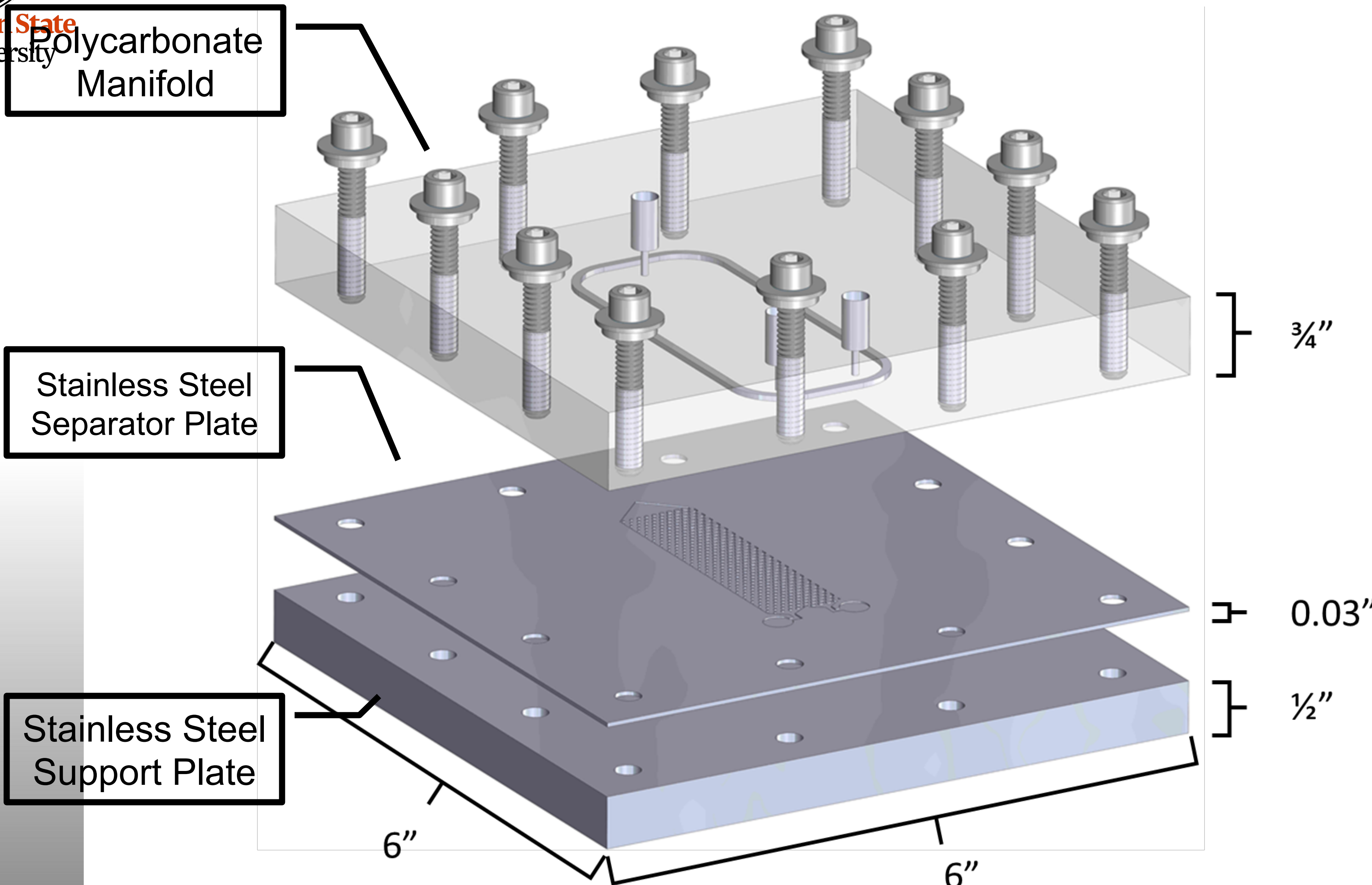


No Surface Tension



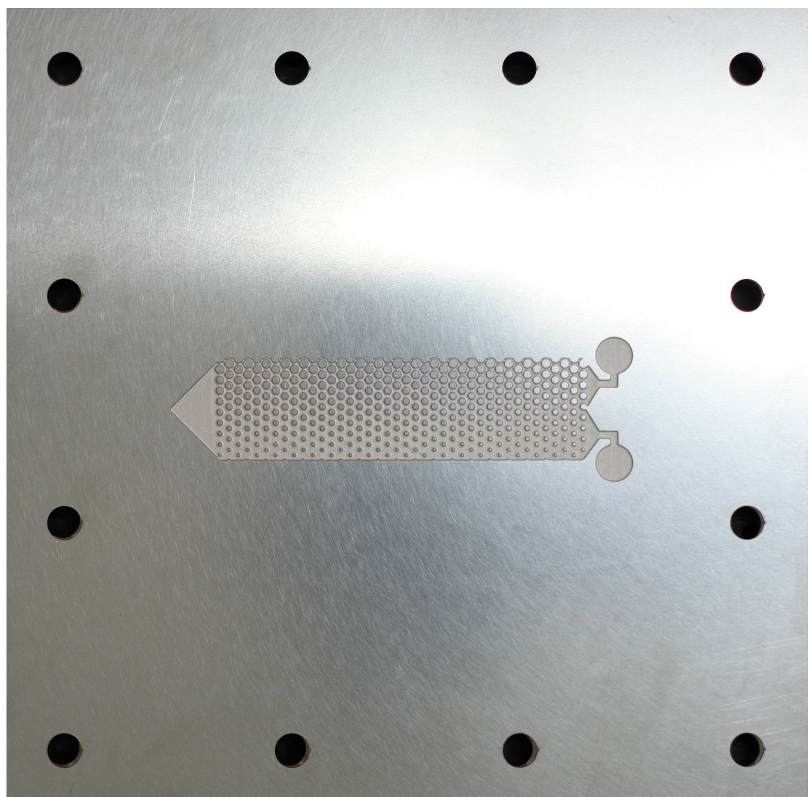

with Surface Tension
Y
Z
X

Separator Assembly

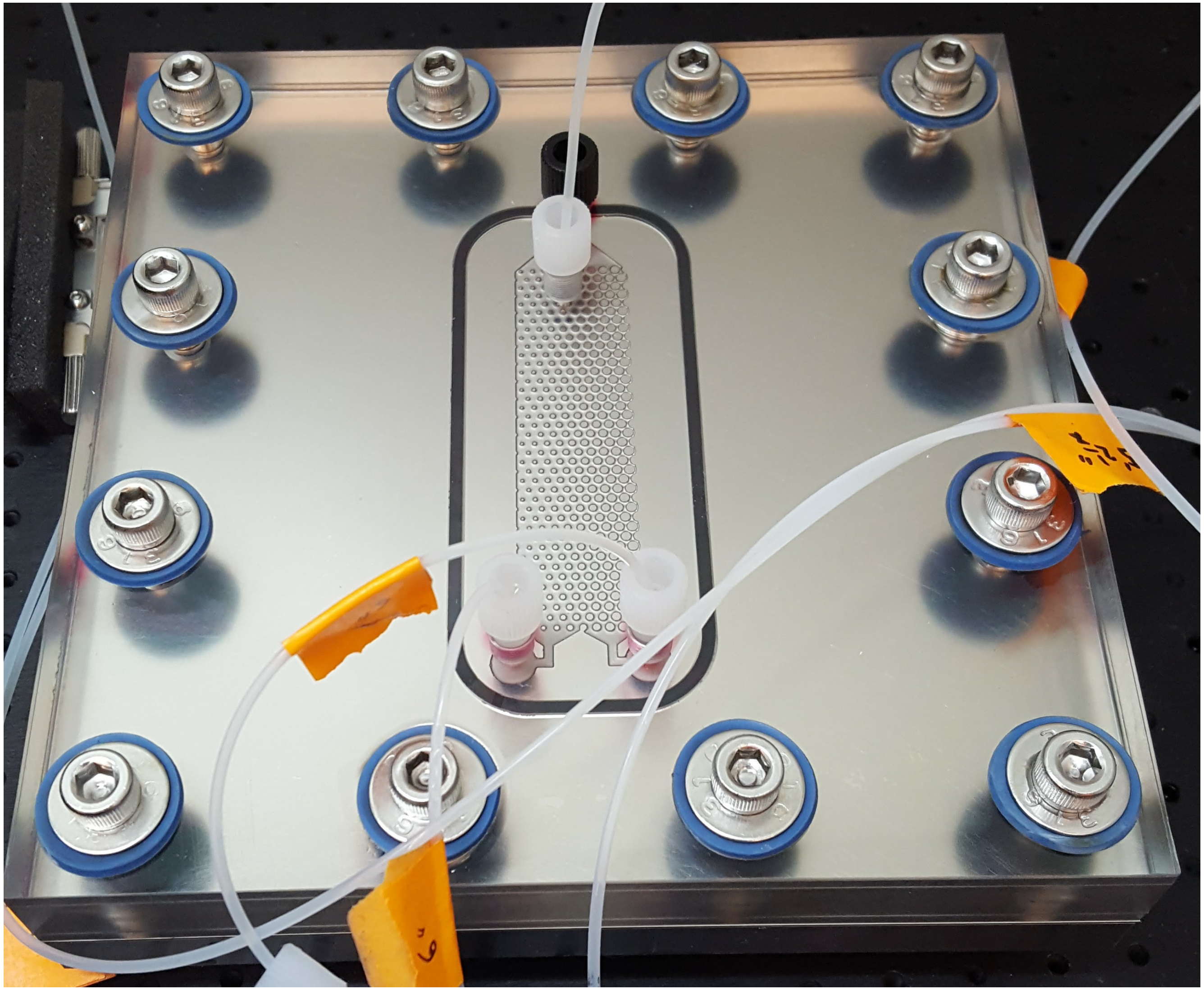


Photochemical Machining

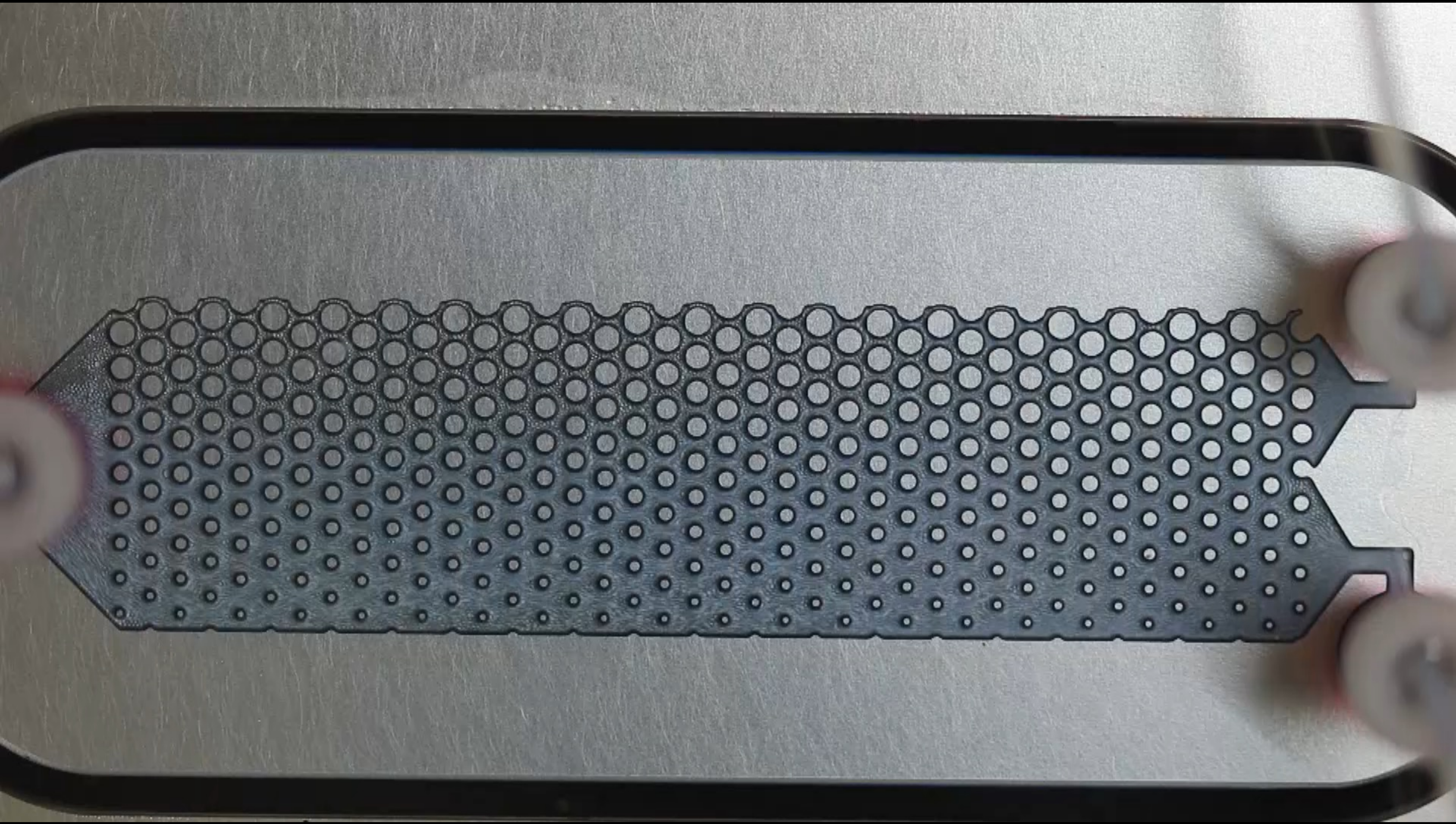
SolidWorks Design → Surface Cleaning → Photo Resist Layered → UV exposure over pattern → Developer → Etchant → Photo resist removal



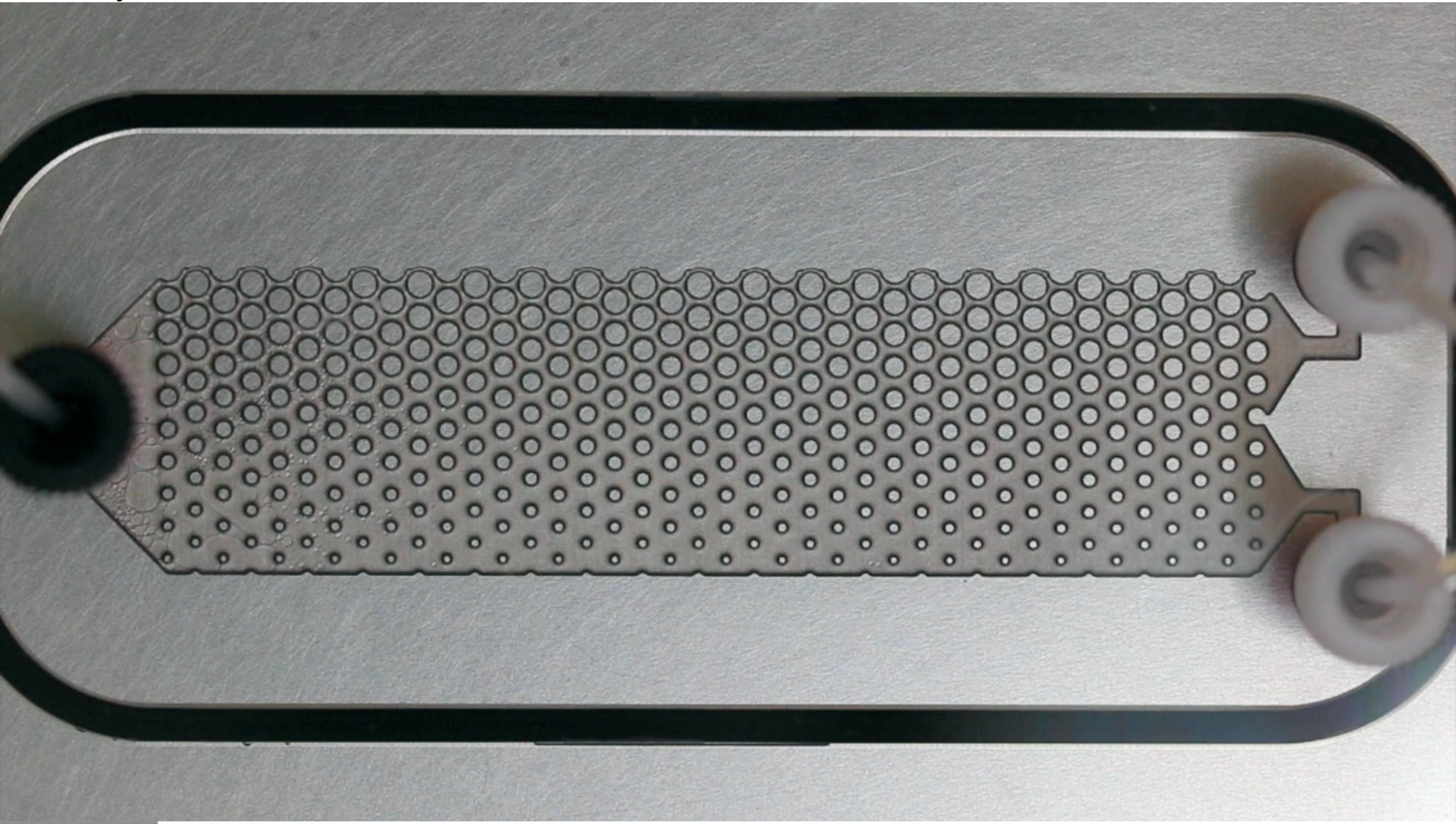
Liquid-Liquid Separator



Liquid-Liquid Separator Flow Behavior – Droplet Flow



Separator Performance



Oregon State University

Oregon State University OSU College of Engineering

People. Ideas. Innovation.

Thank you for your attention!