Swirling Jet Design and Analysis

Flow Parameter Review & Loop Construction

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What is a Swirling Jet?

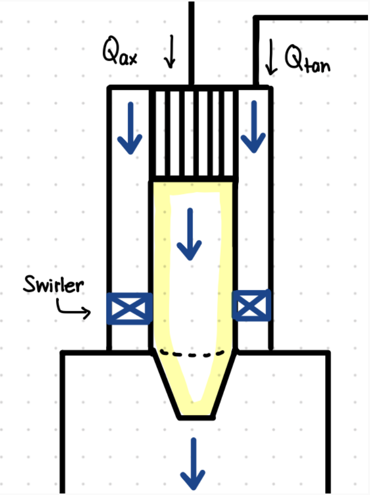
Definition
A **swirling jet** is a fluid jet with azimuthal (rotational) velocity superimposed on the axial flow.

- Characterized by **swirl number** S and **Reynolds number** Re.
- Applications: combustion, mixing enhancement, flow control.

Key Flow Parameters

- **Swirl Number (S):** A dimensionless measure of how much the flow rotates compared to how fast it moves forward.
- **Reynolds Number (Re):** A dimensionless measure comparing inertial and viscous forces, used to determine whether the flow is laminar, transitional, or turbulent.

System Set-up



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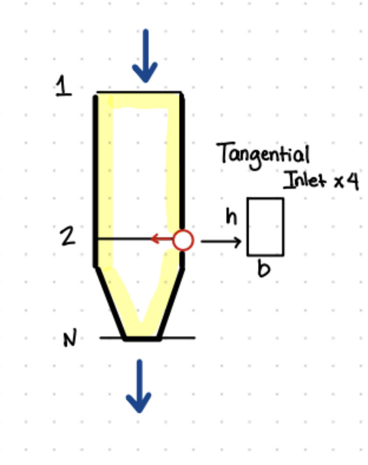


Flowrate Relations

Total volumetric flowrate:

$$Q = Q_{ax} + Q_{tan}$$

Axial and tangential components:

$$Q_{ax} = A_N \bar{v}_{N,ax}, \quad Q_{tan} = A_2 \bar{v}_{2,ax}$$

Cross-sectional areas:

$$A_N = \frac{\pi}{4} D_N^2, \quad A_2 = 4(bh)$$

Conservation of Angular Momentum

Goal: Using known values such as D_2, D_N, and n (number of tangential inlets), determine the velocity at the nozzle exit.

Definition: Angular momentum, in this case, can be thought of as the sum of the tangential velocities multiplied by the radius r over the cross-sectional area:

$$L_z = \iint v_{\theta,z}(r,\theta)\, r\, dr\, d\theta$$

Approximations:

- Tangential inlet: $L_z = nD_2\bar{v}_{\theta,z}/2$
- Nozzle: $v_{\theta,N}(r) = ar$

Angular Momentum: Key Results

Nozzle angular momentum:

$$L_N = 2\pi \int_0^{D_N/2} v_{\theta,N}(r)\, r\, dr = 2\pi a \left(\frac{D_N^3}{24}\right)$$

With $v_{\theta,N}(r) = ar$, we have:

$$L_N = 2\pi a \left(\frac{D_N^3}{24}\right) = \frac{\pi \bar{v}_{\theta,N} D_N^2}{6}$$

Equating $L_N = L_z$:

$$\frac{\pi \bar{v}_{\theta,N} D_N^2}{6} = \frac{n D_2 \bar{v}_{\theta,z}}{2}$$

Final Result

$$\boxed{\bar{v}_{\theta,N} = \frac{3 n D_2 \bar{v}_{\theta,z}}{\pi D_N^2}}$$

Reynolds Number

$$\boxed{\mathrm{Re} = \frac{\rho D_N \bar{v}_N}{\mu}} \tag{1}$$

Literature Values:

- **Billant et al. (1998):** Laminar swirling jets studied in the range $300 < \mathrm{Re} < 1200$, examining bubble and cone breakdown states.
- **Oberleithner et al. (2011):** Turbulent regime at $\mathrm{Re}_D = 20{,}000$.
- **Note:** These studies may define Re differently.

Swirl Number and Critical Conditions

$$\boxed{S = \frac{\bar{v}_{N,\theta}}{\bar{v}_{N,ax}}} \tag{2}$$

Critical Swirl Numbers:

- **Billant et al. (1998):** Investigated a free swirling water jet in the range $300 < \mathrm{Re} < 1200$. Breakdown occurred at a critical swirl number
$$S_c \approx 1.3\text{–}1.4,$$
nearly independent of Reynolds number.
- **Oberleithner et al. (2011):** For a turbulent jet at $\mathrm{Re}_D = 20{,}000$, a critical value of
$$S_{\mathrm{crit}} = 0.88$$
was observed due to instabilities.
- **Note:** These studies may define S differently.

Summary: Design Parameters

Key Governing Equations:

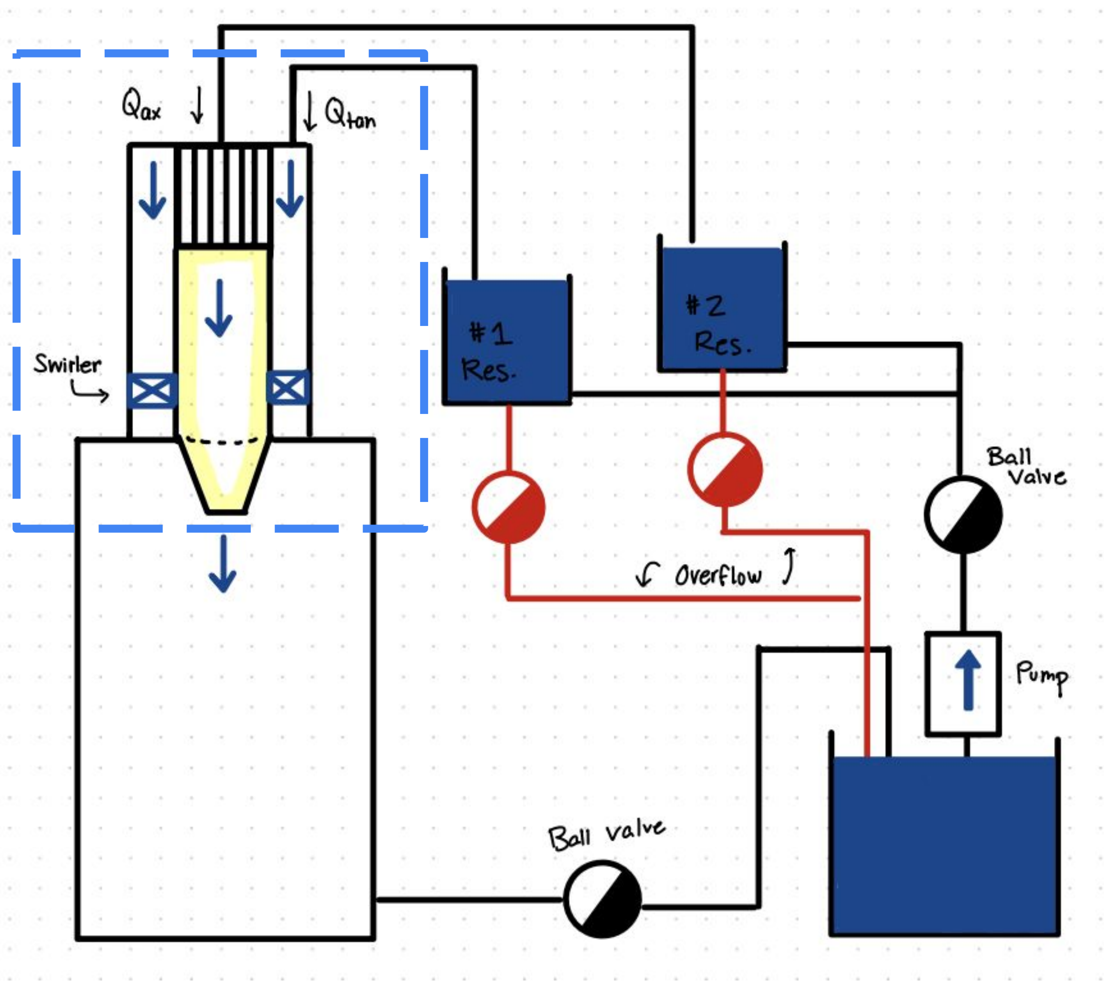
$$\mathrm{Re} = \frac{\rho D_N \bar{v}_N}{\mu}$$

$$S = \frac{\bar{v}_{N,\theta}}{\bar{v}_{N,ax}}$$

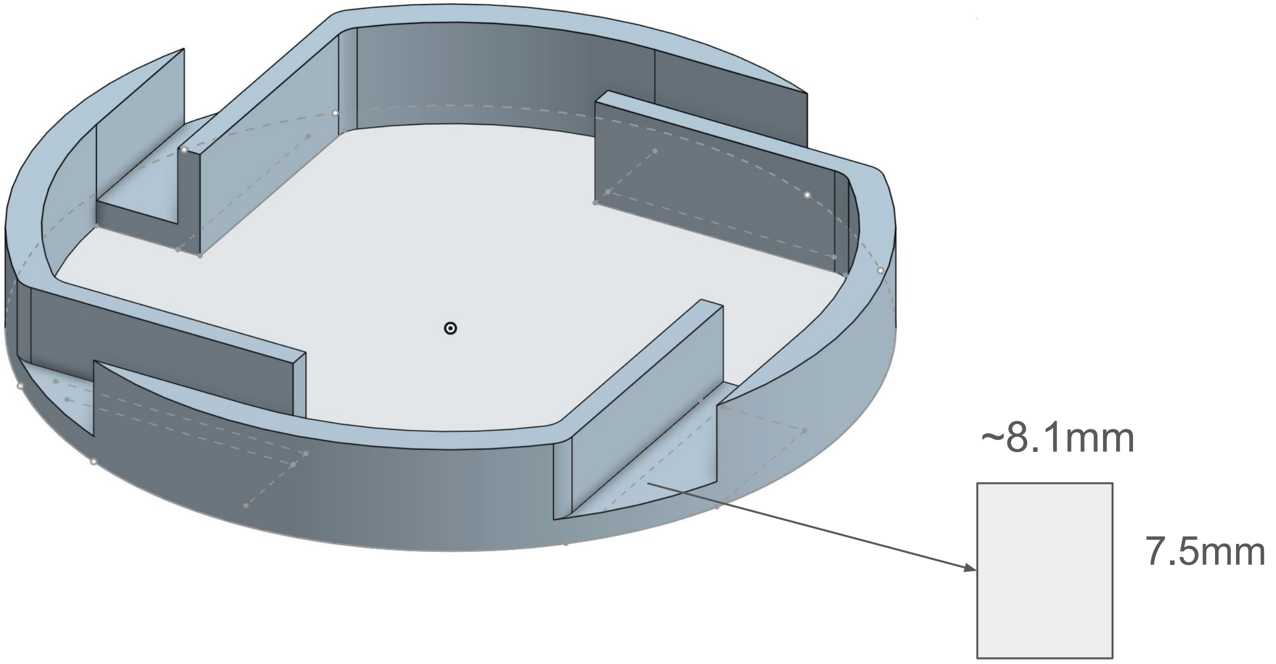
$$\bar{v}_{\theta,N} = \frac{3nD_2\bar{v}_{\theta,z}}{\pi D_N^2}$$

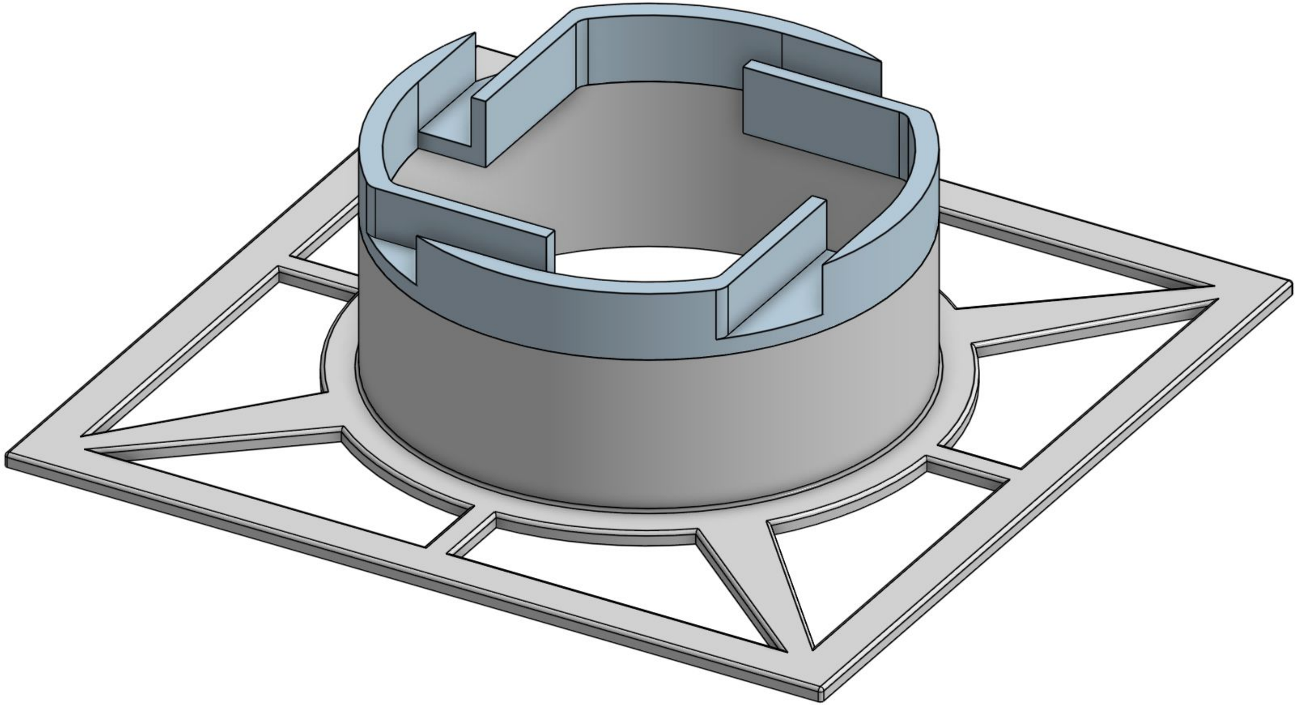
Critical Values:

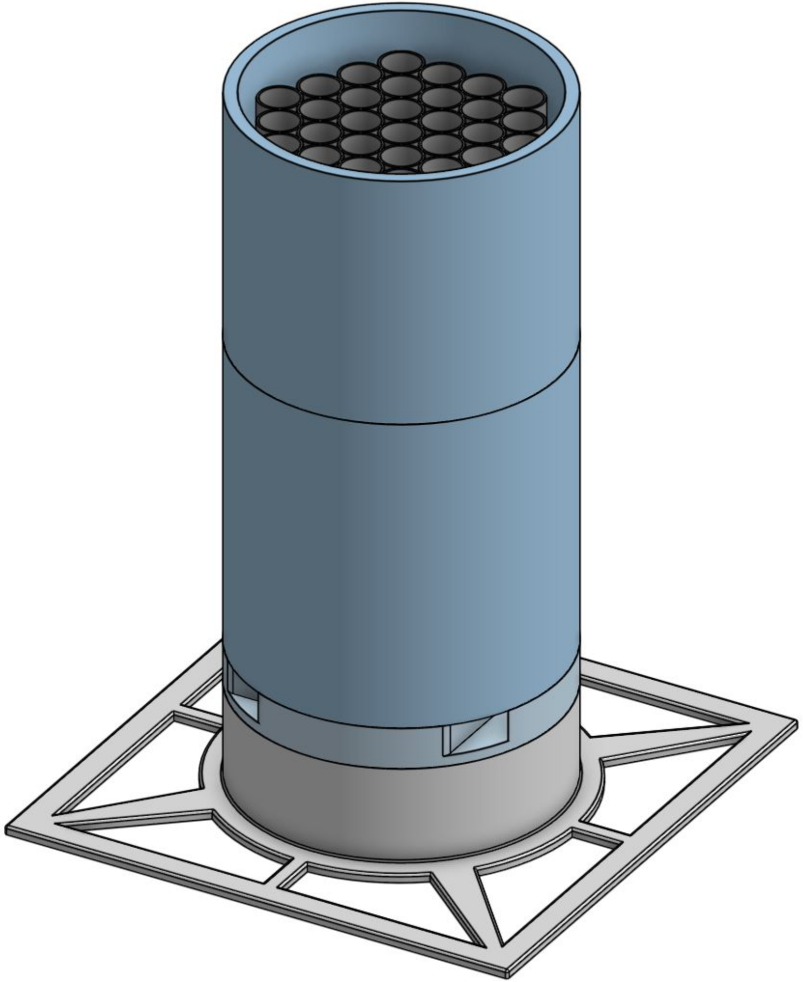
- Laminar regime: $S_c \approx 1.3 - 1.4$ (nearly Re-independent)
- Turbulent regime: $S_{\mathrm{crit}} \approx 0.88$

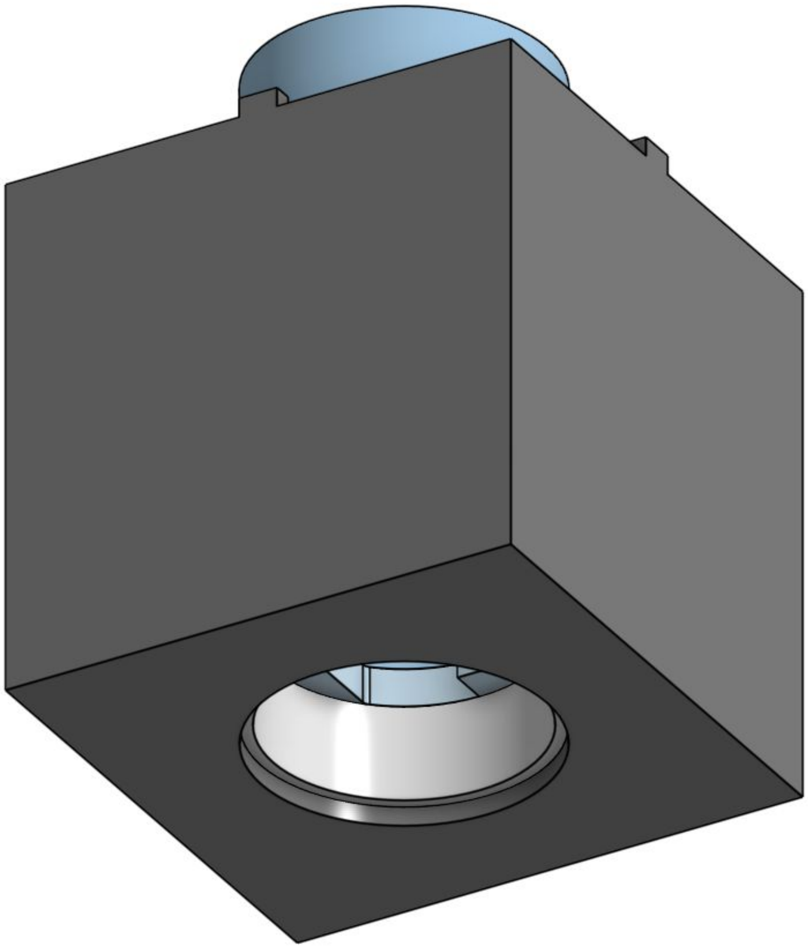


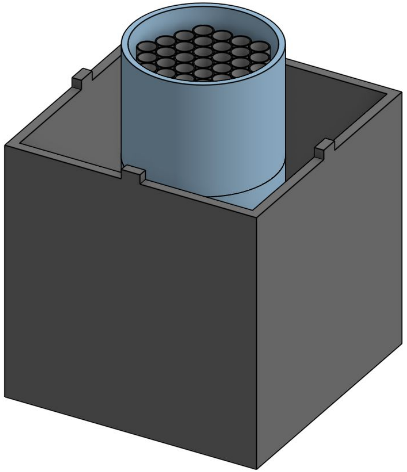
Qax
Qtan
Swirler
#1 Res.
#2 Res.
Ball Valve
Overflow
Pump
Ball valve

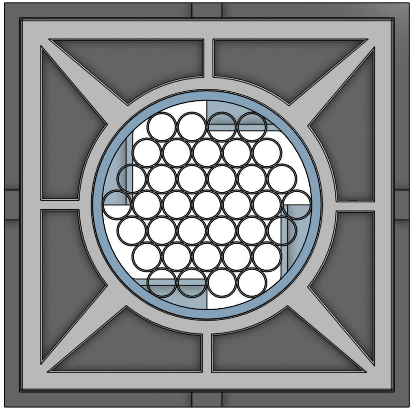

~8.1mm
7.5mm

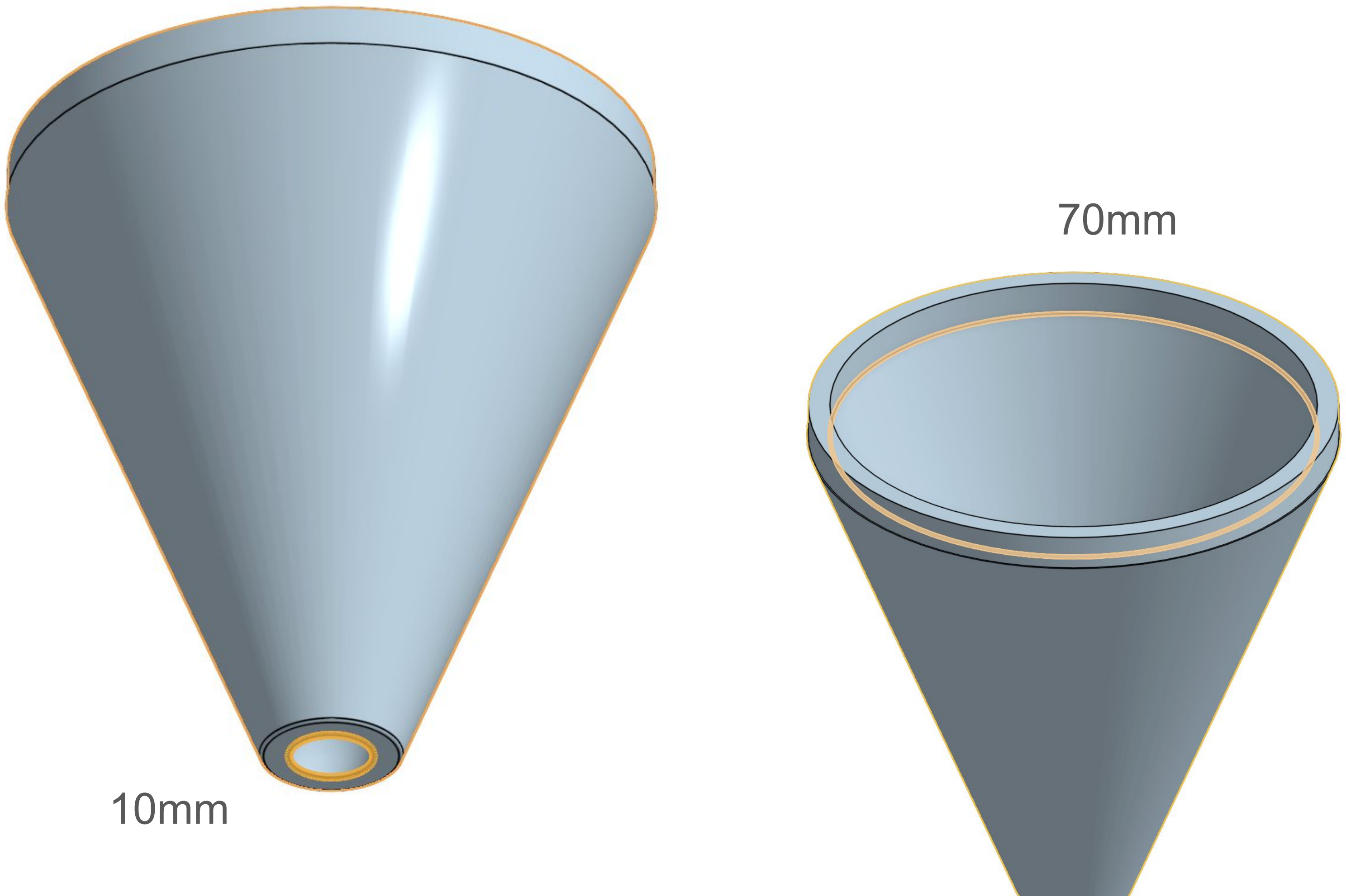


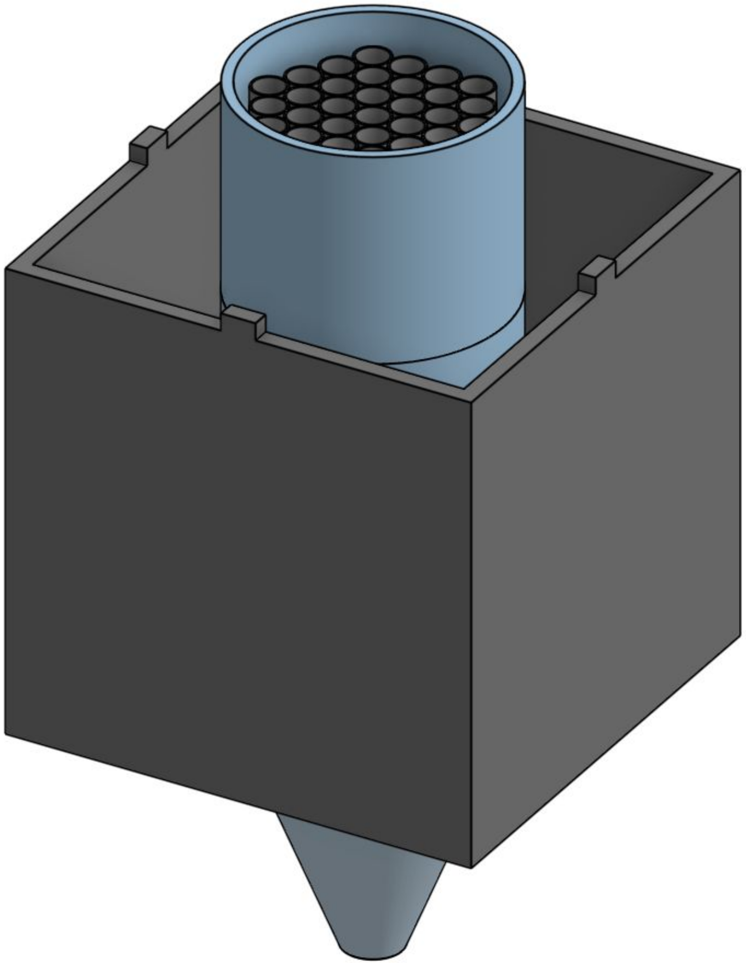
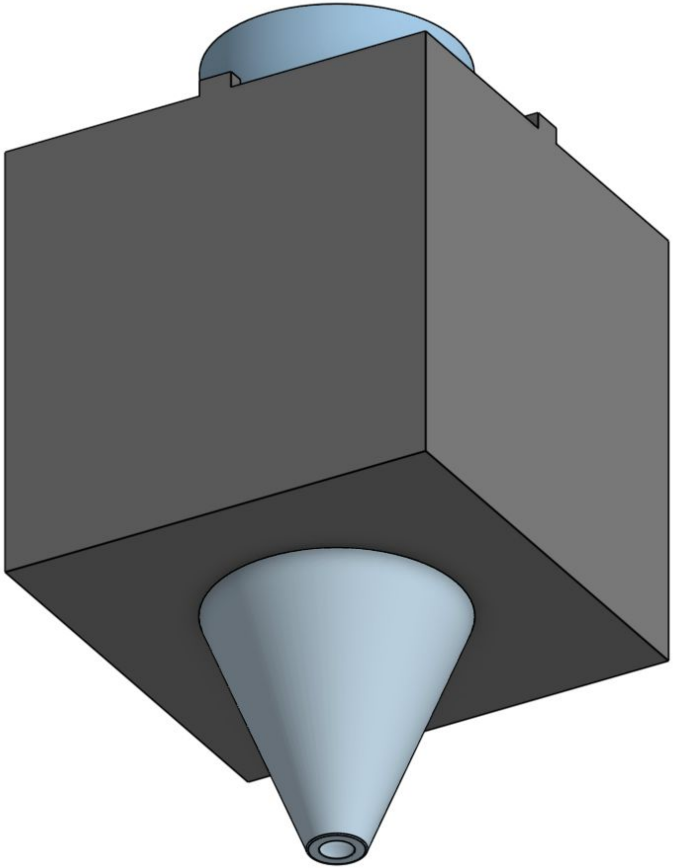


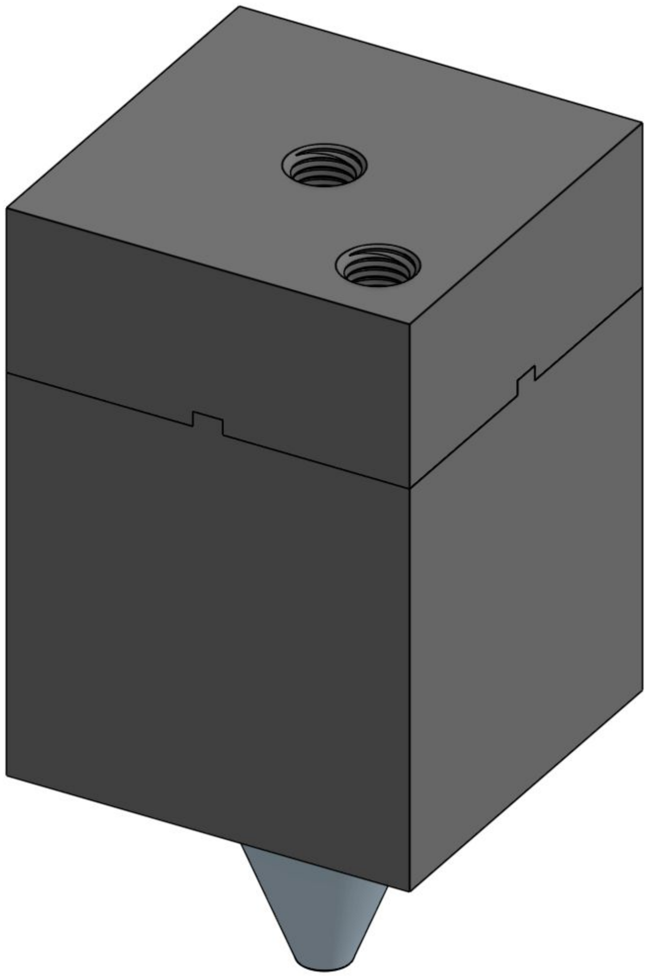


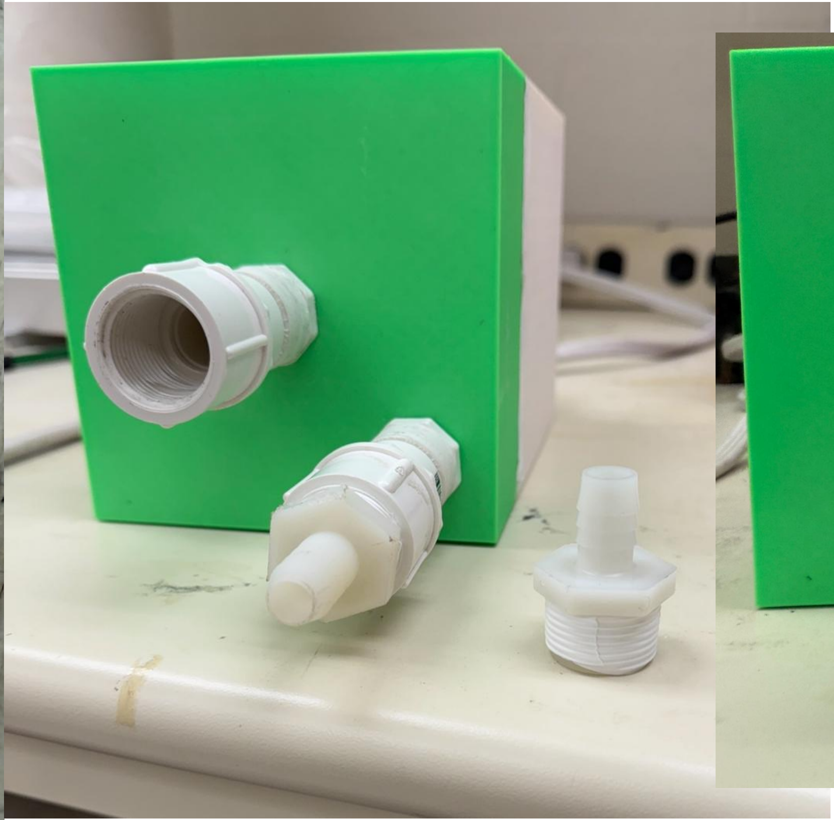
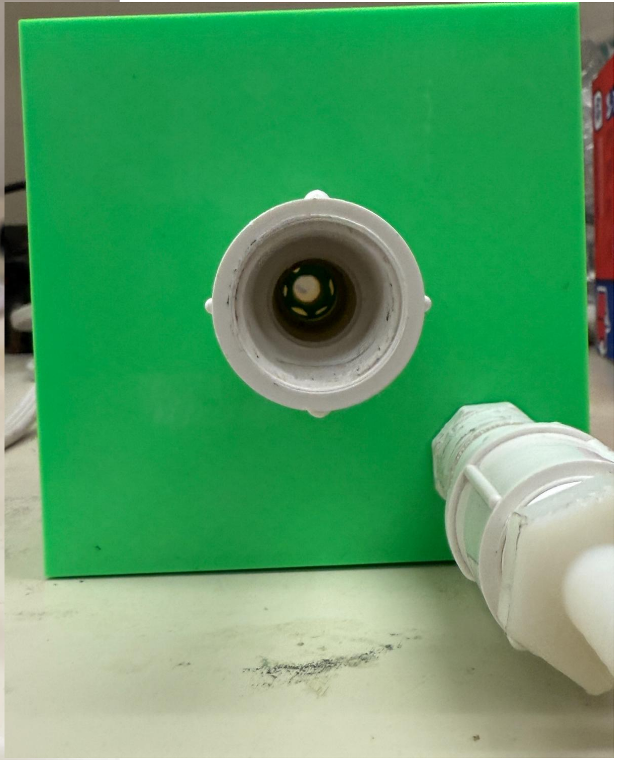


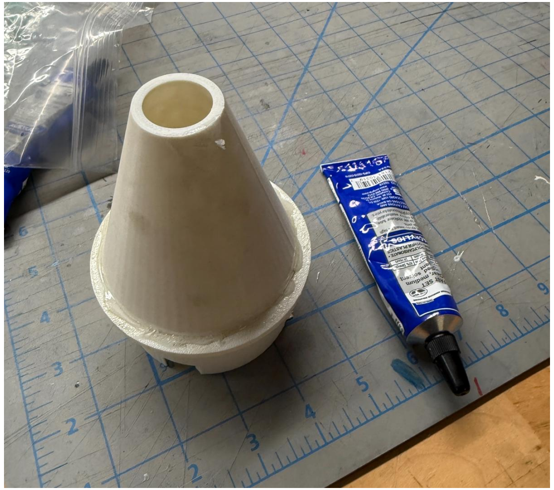


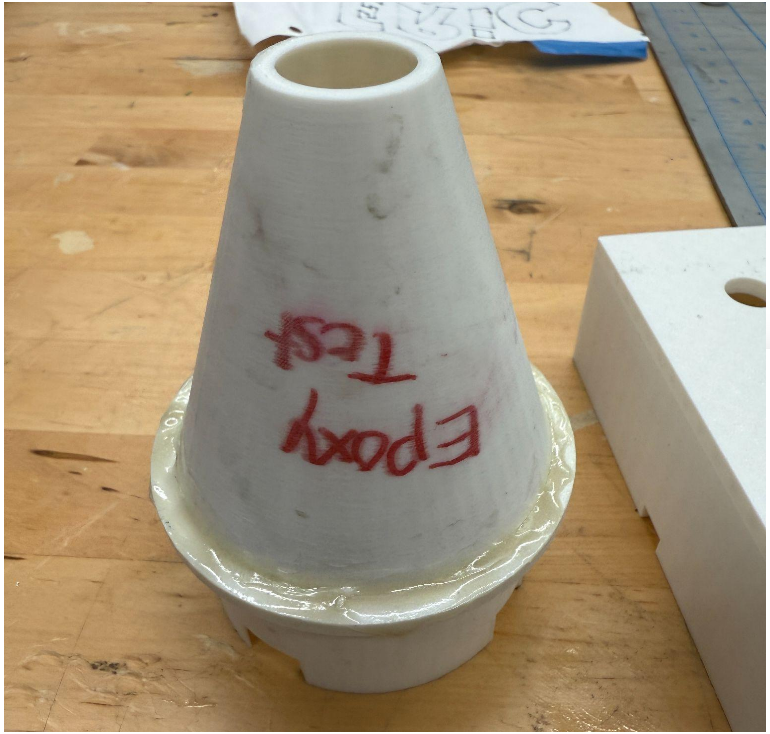

70mm
10mm



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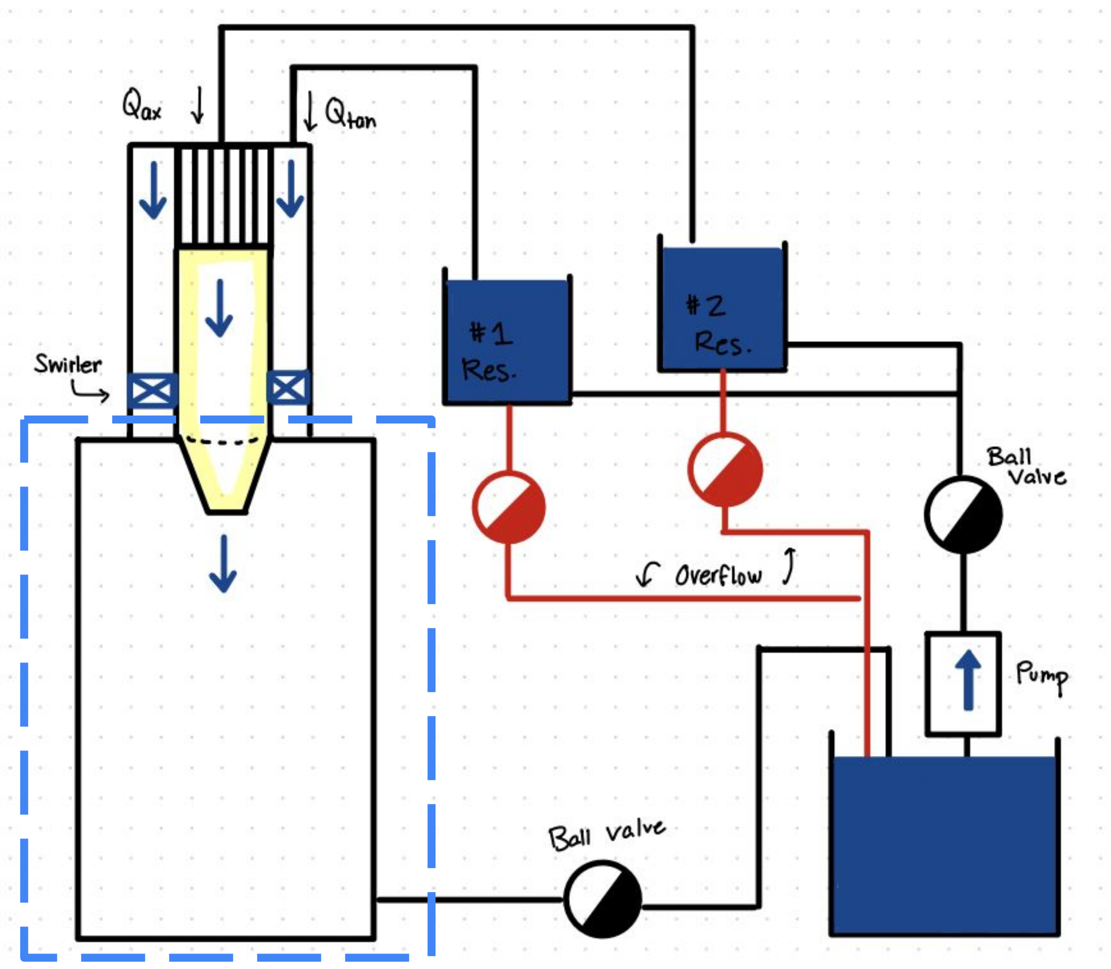

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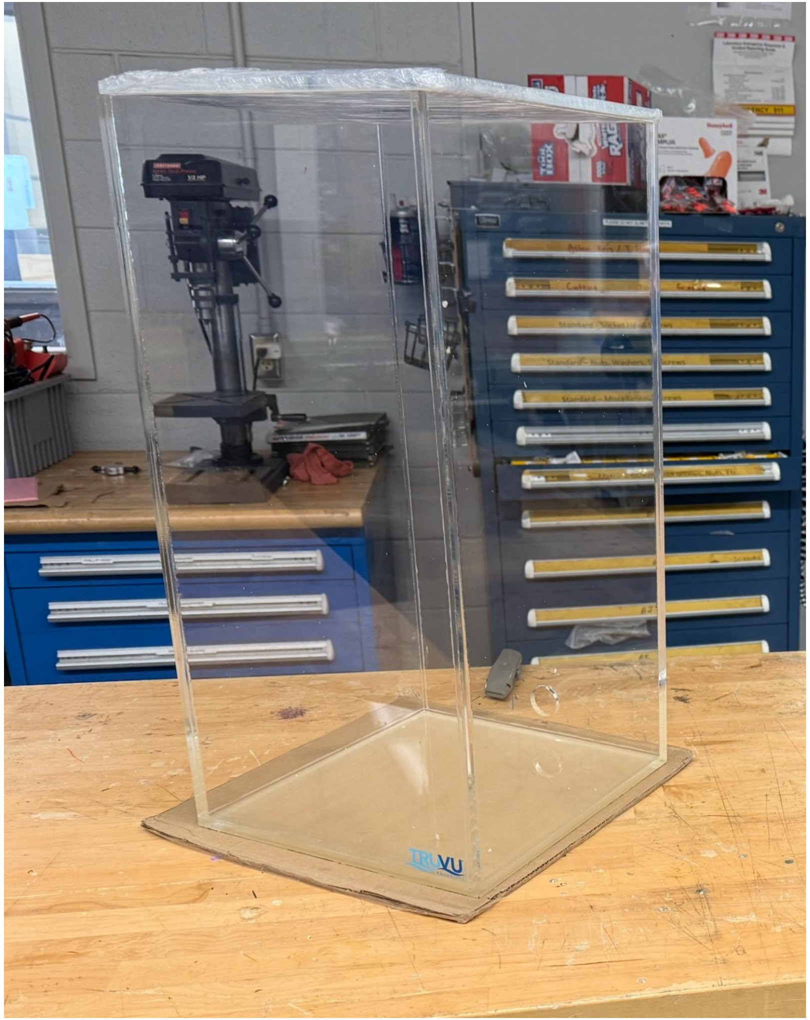

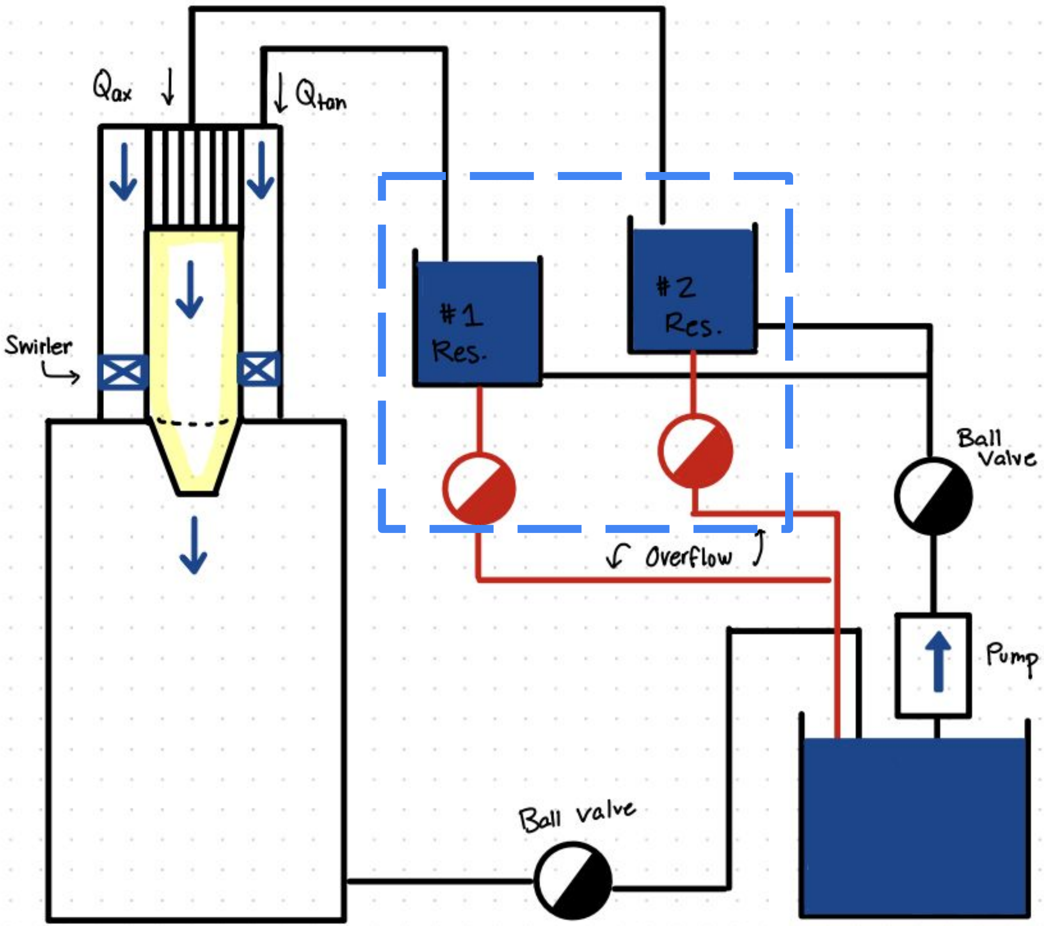

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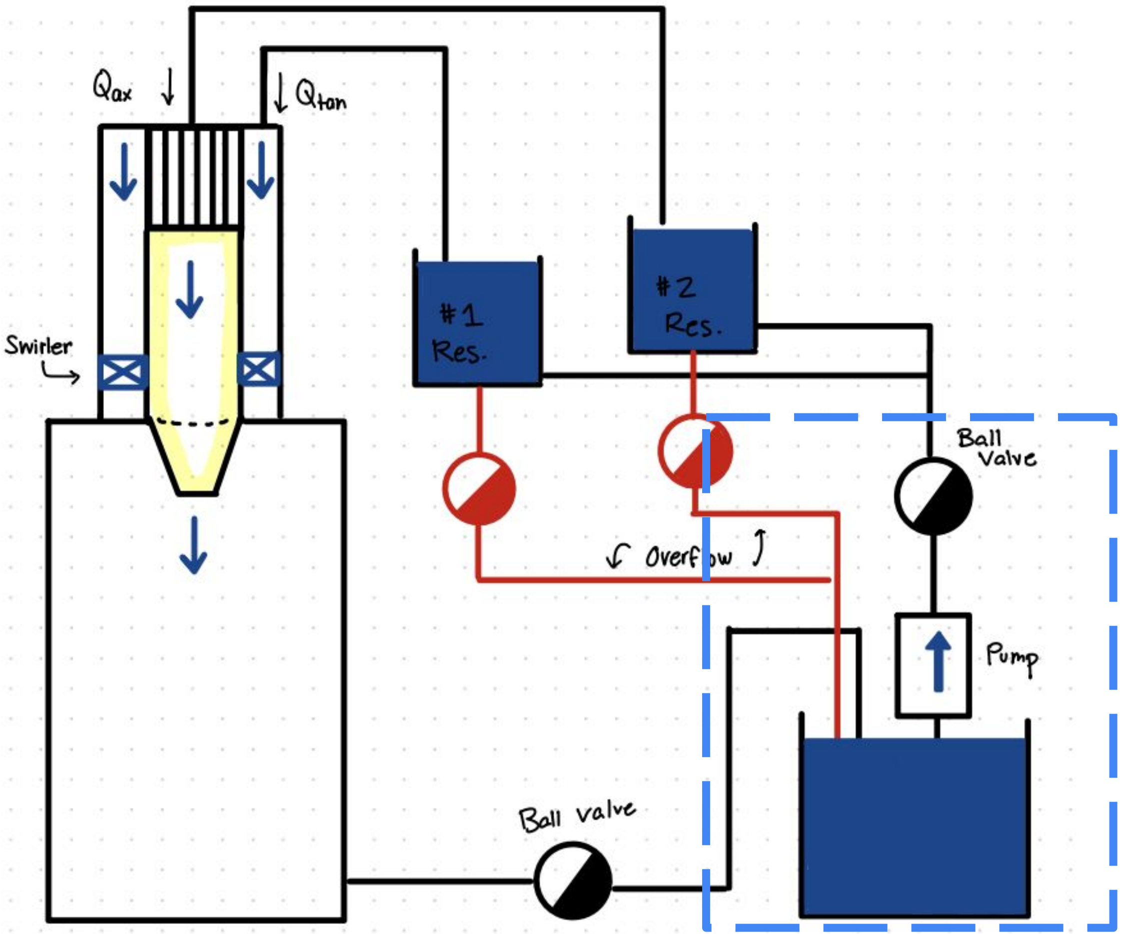

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BRUTE