Reporter Team

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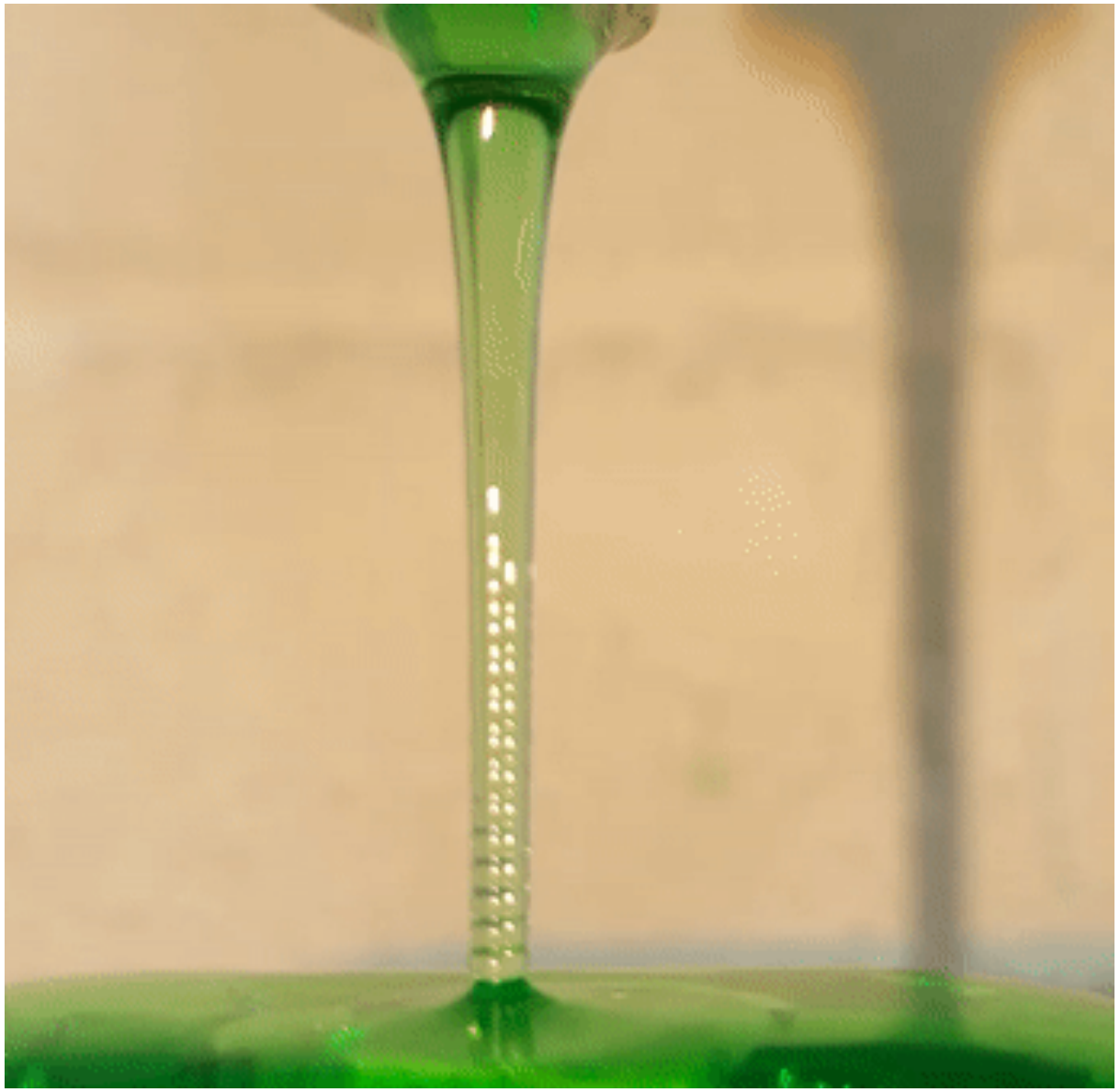
Problem 8

Rippled Water Columns

Problem Statement

When a vertical water jet hits a surface, ripples may appear. If certain conditions are met, the ripple structure is pronounced, steady and very reproducible.

Describe the phenomenon. What properties of the fluid and the flow can be deduced from the observations?



Characterizing a flow

The quantity of fluid that passes a point per unit of time.

$$Flow = \frac{Volume}{Time} = Area \cdot Velocity$$

Steady and **turbulent** states ⟶ Reynolds Number (Re)

Laminar and Turbulent flows

$$Re = \frac{\rho \cdot v \cdot l}{\mu}$$

$$\frac{\text{Inertial Forces}}{\text{Viscous Forces}}$$

Rayleigh-Plateau Instability

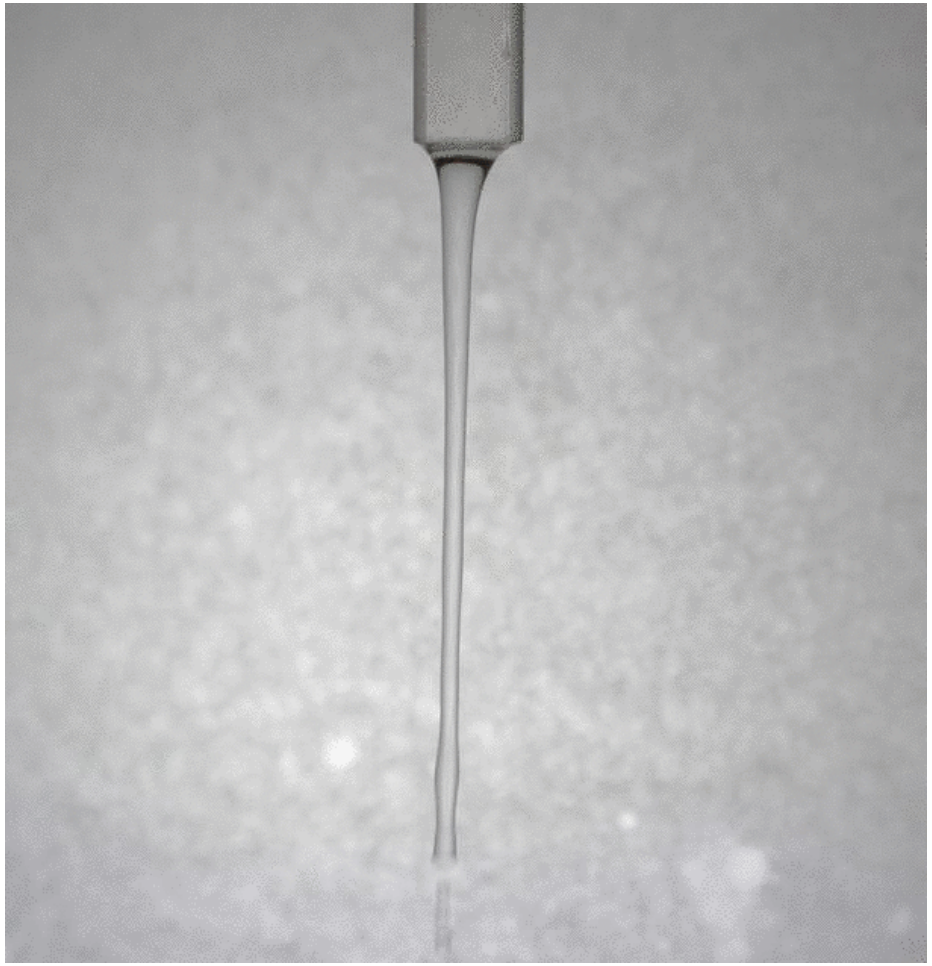
Surface tension **σ**

leads to

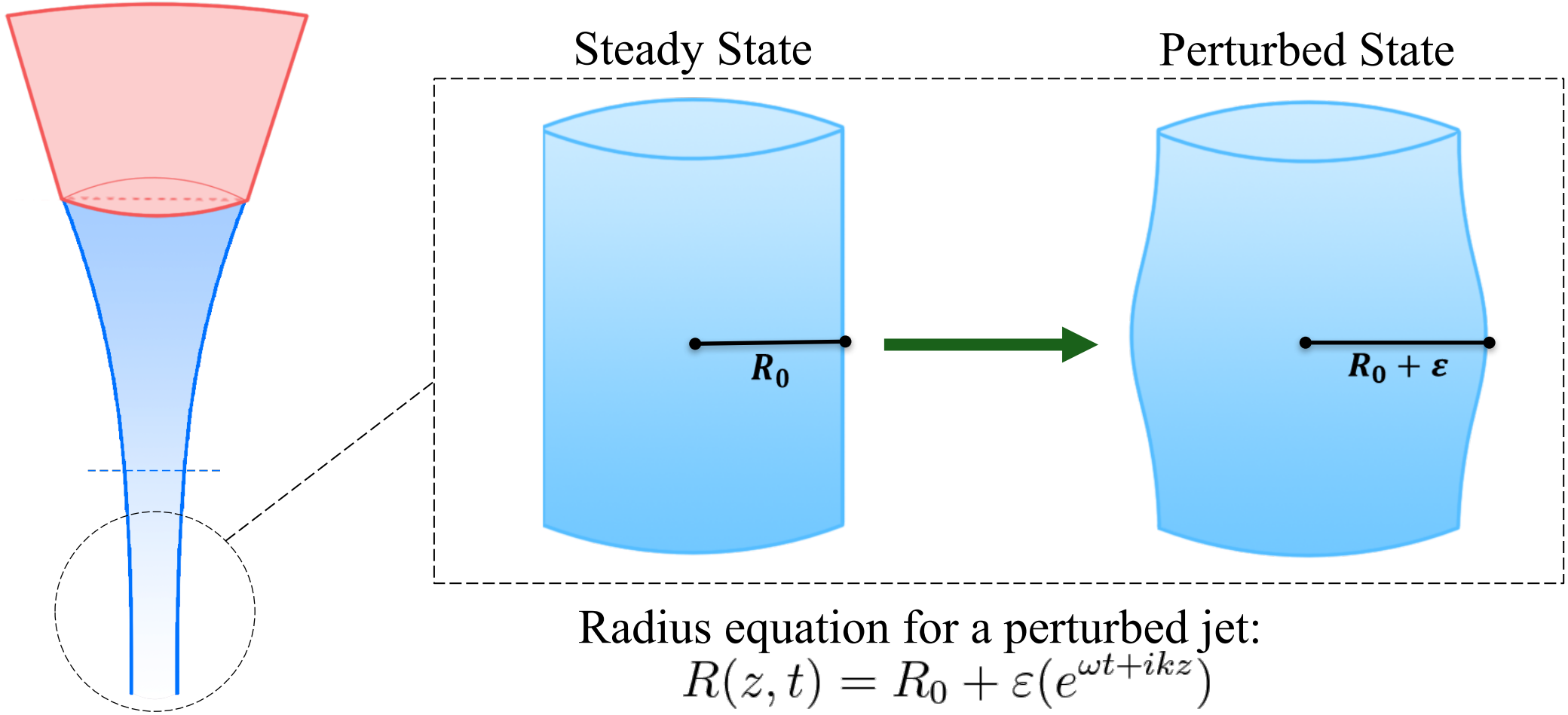
Oscillations

resulting into

Droplets



Perturbations on the jet



Radius equation for a perturbed jet:

$$R(z,t) = R_0 + \varepsilon(e^{\omega t + ikz})$$

Breslouer, O. (2010). *Rayleigh-Plateau Instability: Falling Jet, Analysis and Applications.* Princeton University. www.princeton.edu/~stonelab/Teaching/Oren%20Breslouer%20559%20Final%20Report.pdf

Its governing equations

Momentum: $$\omega R(r) = -\frac{1}{\rho}\frac{dP(r)}{dr} \quad , \quad \omega Z(r) = -\frac{ik}{\rho}P(r)$$

Continuity: $$\frac{dR(r)}{dr} + \frac{R(r)}{r} + ikZ(r) = 0$$

Breslouer, O. (2010). *Rayleigh-Plateau Instability: Falling Jet, Analysis and Applications.* Princeton University. www.princeton.edu/~stonelab/Teaching/Oren%20Breslouer%20559%20Final%20Report.pdf

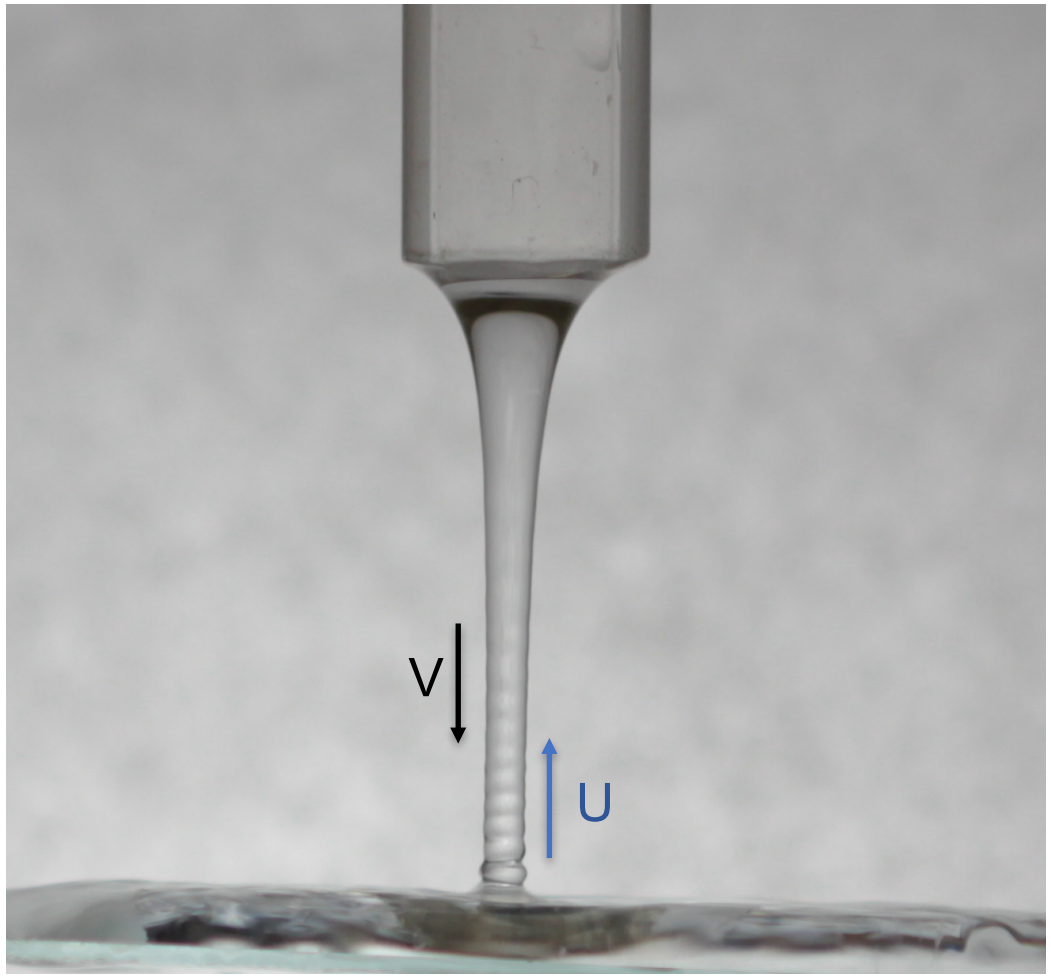
Dispersion relation

$$\omega^2 = \frac{\sigma}{\rho}\frac{k}{R_0^2}\frac{I_1(kR_0)}{I_0(kR_0)}(1-k^2R_0^2)$$

$$\begin{cases} kR_0 < 1 \rightarrow e^{i(\omega t + kz)} \\ kR_0 > 1 \rightarrow e^{\omega t + ikz} \end{cases}$$

Breslouer, O. (2010). *Rayleigh-Plateau Instability: Falling Jet, Analysis and Applications.* Princeton University. www.princeton.edu/~stonelab/Teaching/Oren%20Breslouer%20559%20Final%20Report.pdf

Jet and wave velocities



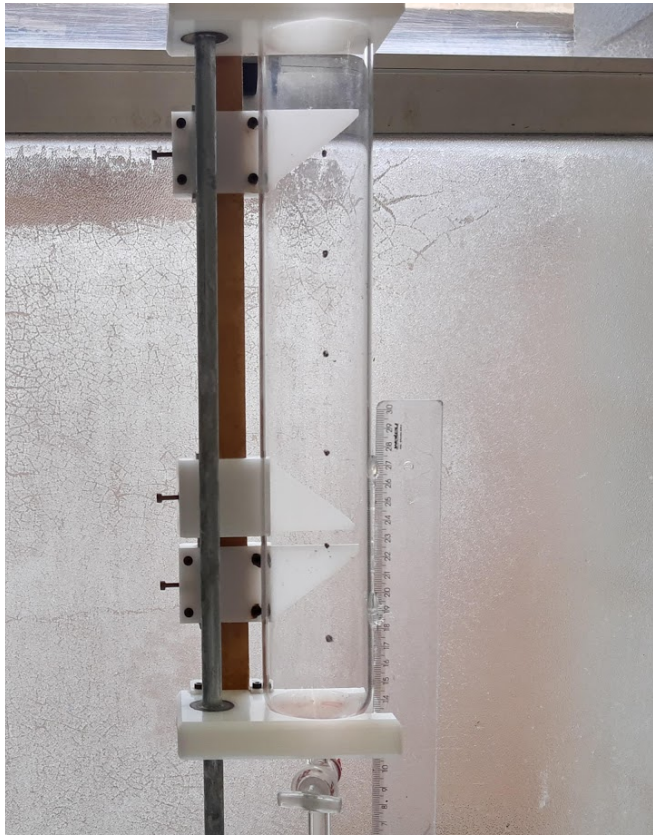
$$V^2 \sim U^2 = \frac{\omega^2}{k^2}$$

$$\frac{\omega^2}{k^2} = \frac{\sigma}{\rho}\frac{1}{kR_0^2}\frac{I_1(kR_0)}{I_0(kR_0)}(1-k^2R_0^2)$$

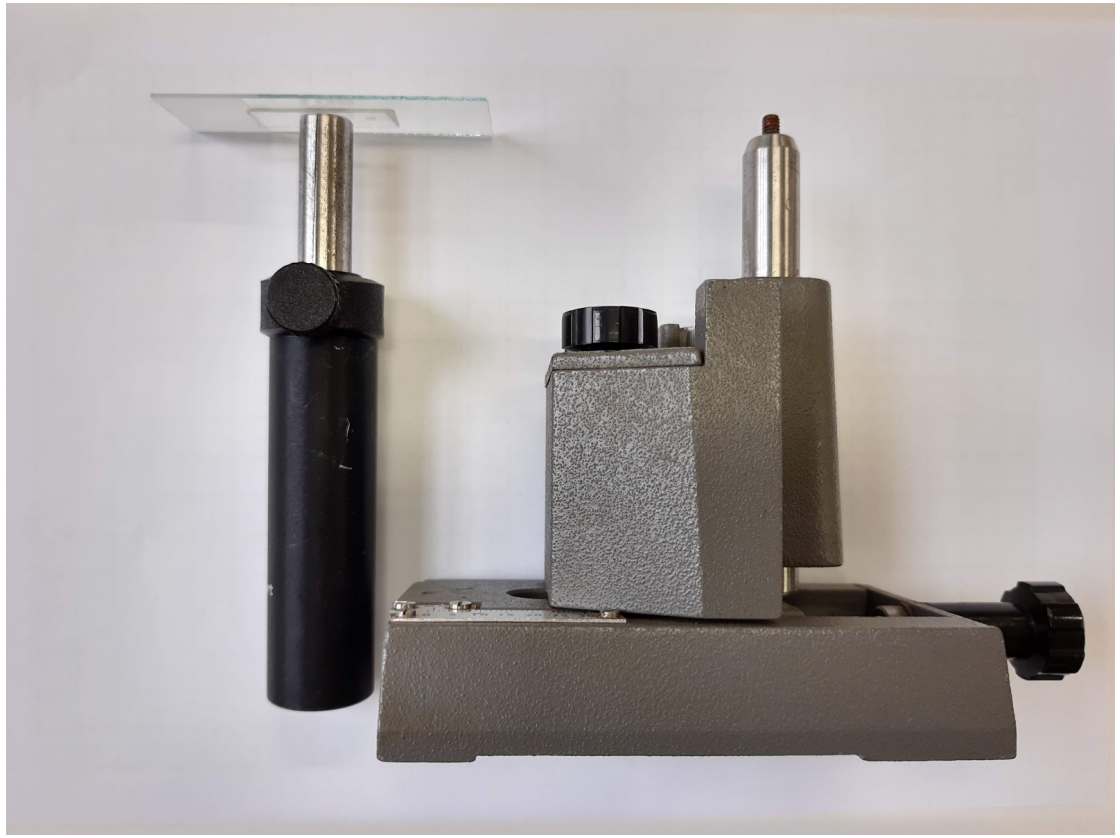
Results

Setup

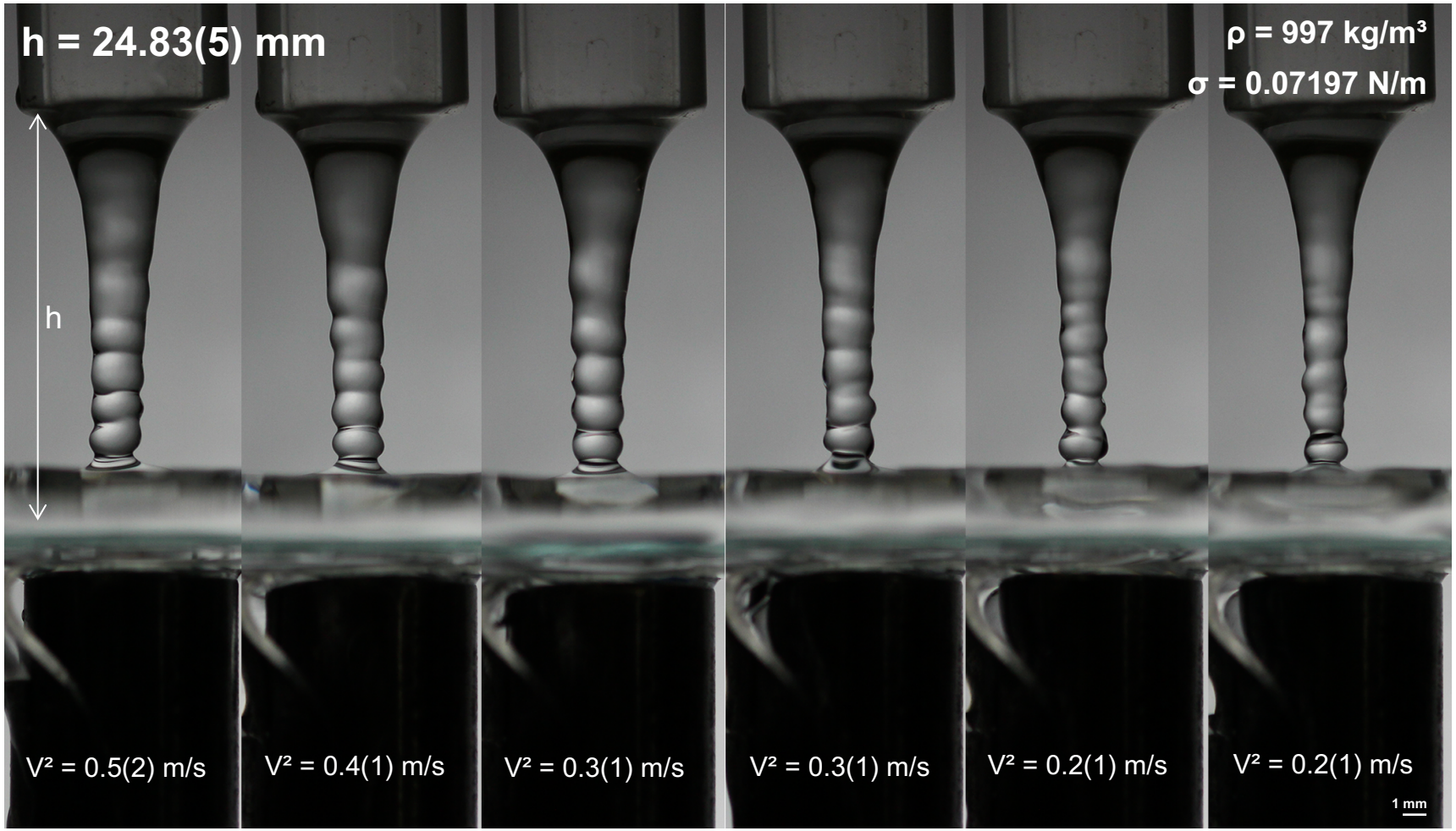
Open glass column with register



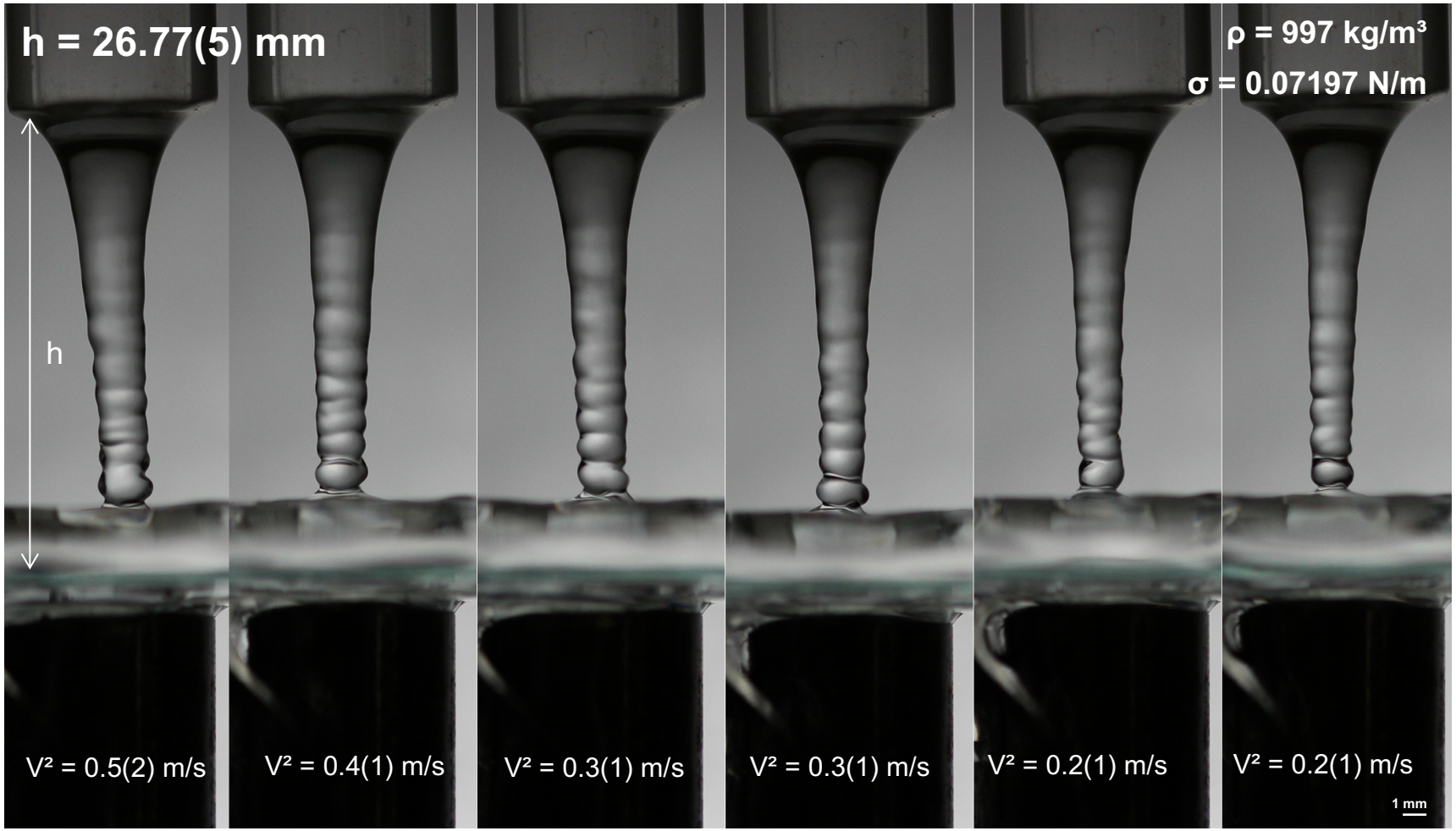
Glass surface + height adjustaments supports



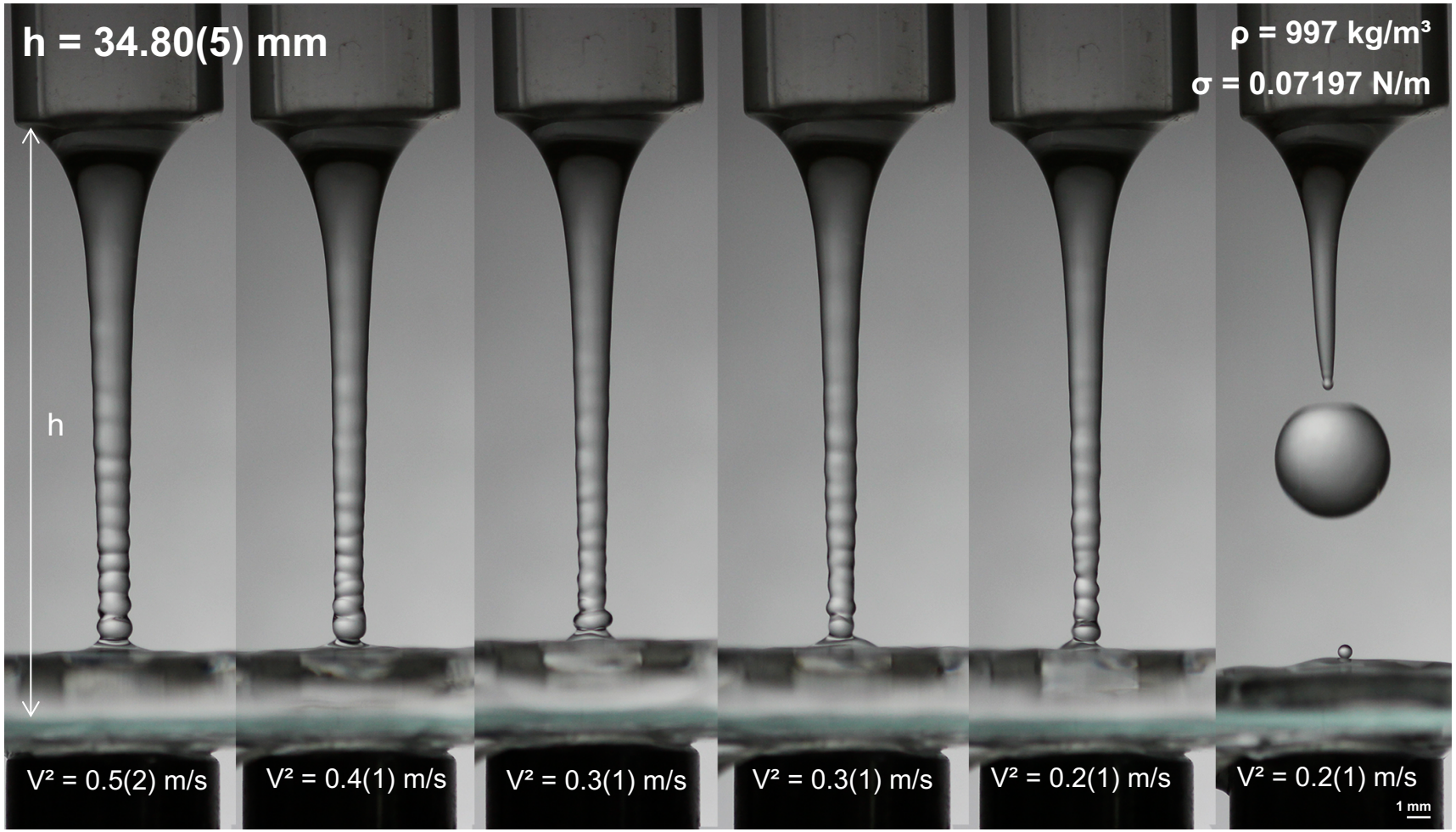
Nozzle to surface height variation



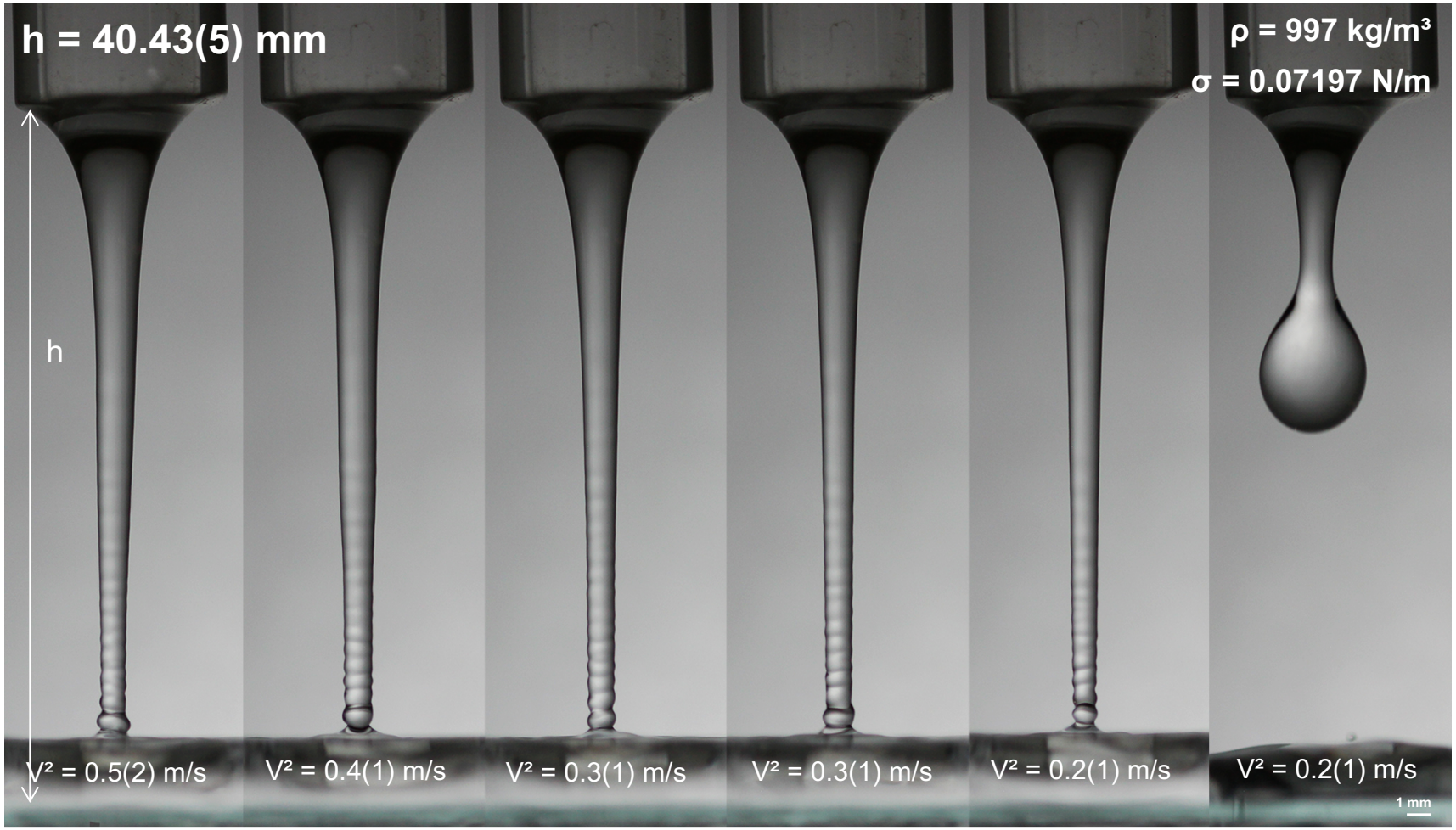
Nozzle to surface height variation



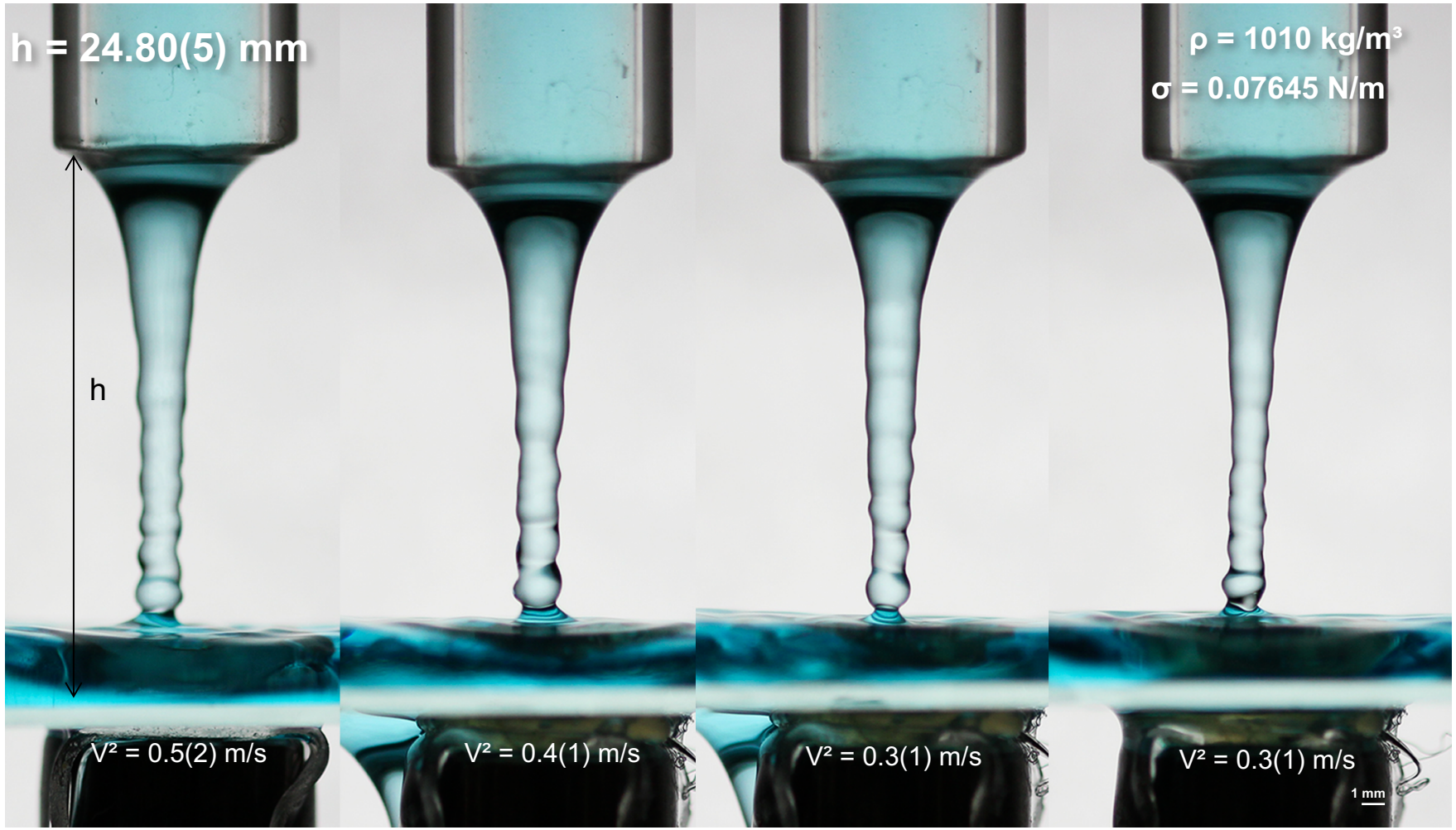
Nozzle to surface height variation



Nozzle to surface height variation

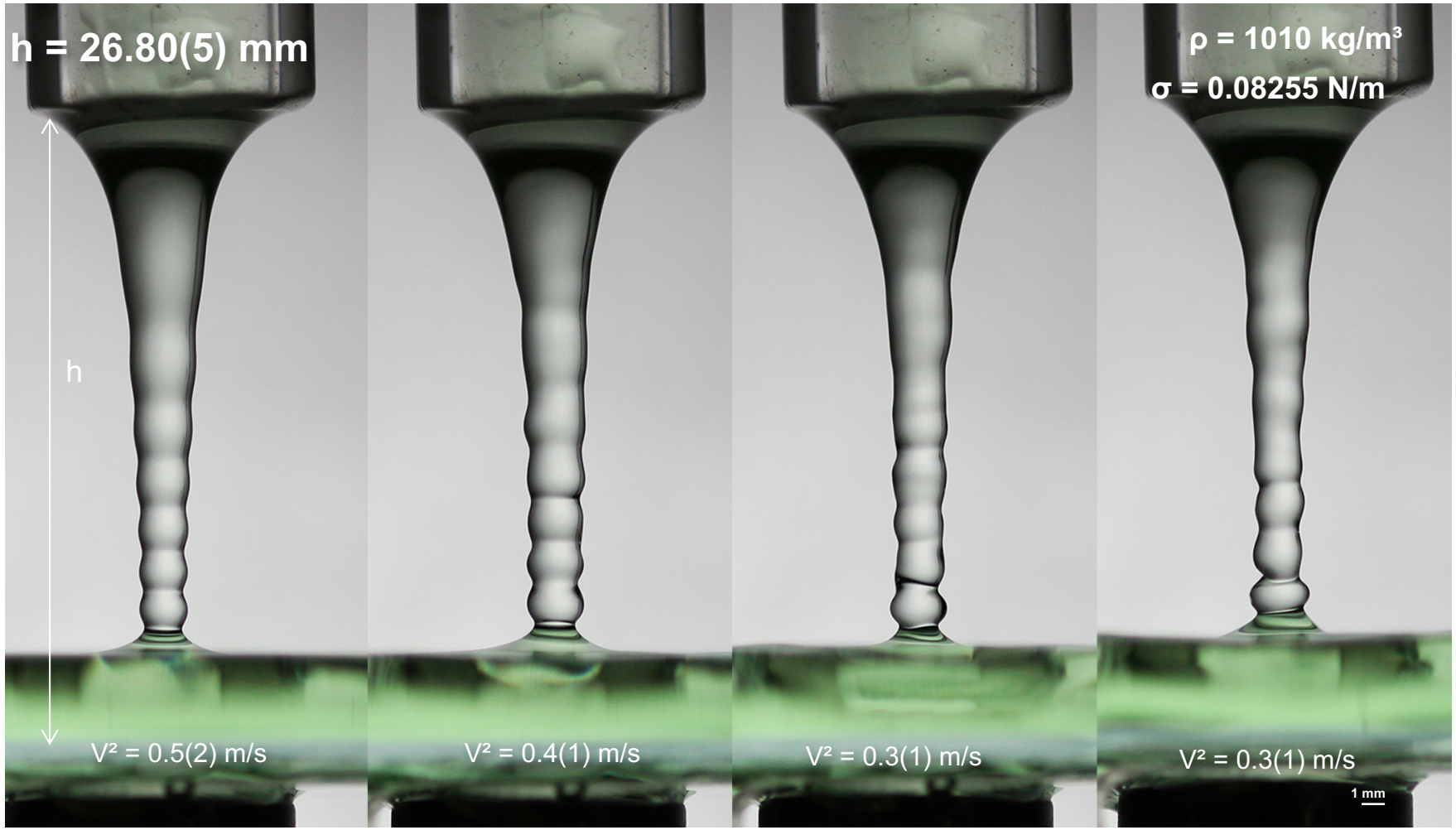


0,03M Sugar solution

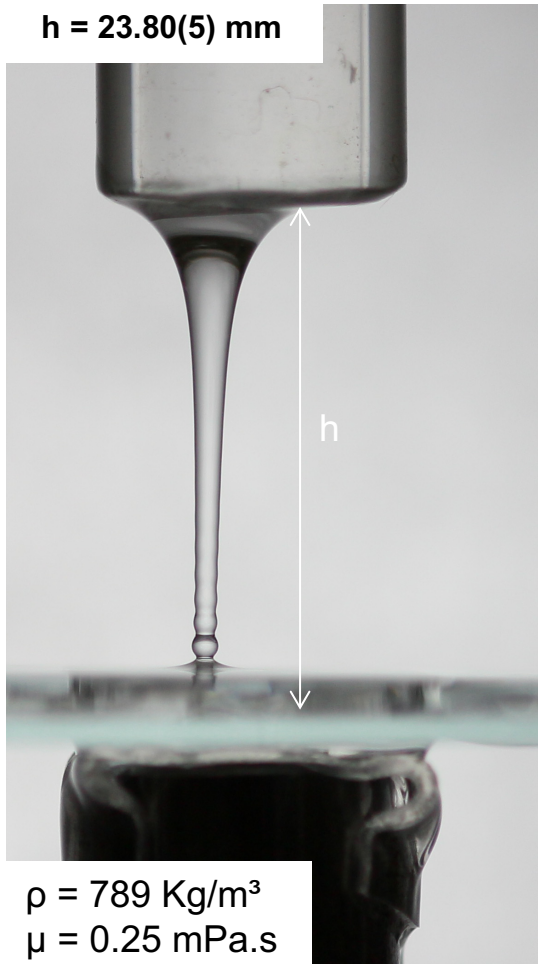


Problem 8

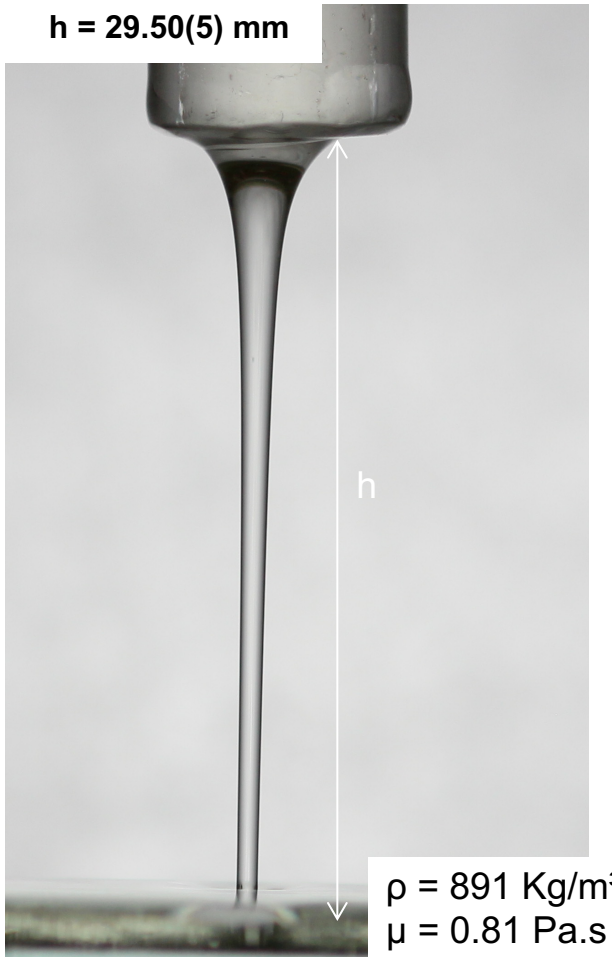
0,2M Salt solution



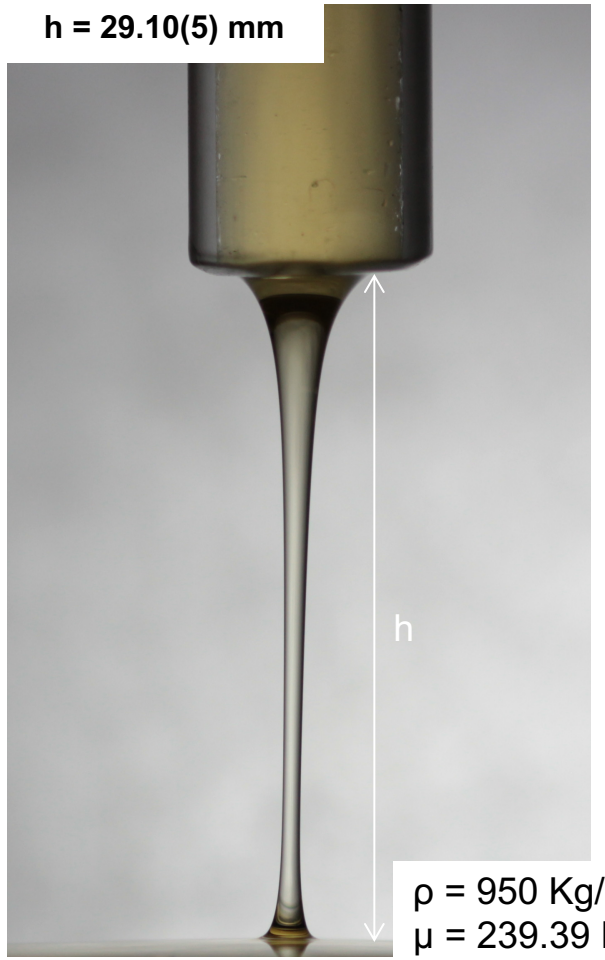
Ethanol



Kitchen soy oil



Car oil



Problem 8

Solving dispersion for σ/ρ factor

Water jet at **h= 40.34(5) mm**

Jet Velocity V² (m²/s²)	Wavenumber k (mm^{-1})	σ/ρ 10^{-5}(m³/s²)
0.5(2)	0.80(4)	7.2(8)
0.4(1)	0.79(4)	6.4(7)
0.3(1)	0.78(4)	5.4(7)
0.3(1)	0.98(4)	4.5(3)
0.2(1)	0.75(4)	3.5(4)

$\sigma/\rho_{water} = 0.000072\ m^3/s^2$

Discussions

- Changing of pressure due to open glass column affecting the flow velocity and ripple reproducibility;
- Effect of changing the surface tension σ;
- Different liquids may have the same σ/ρ ratio.

Conclusions

- A relation between some properties of the fluid can be expressed by the σ/ρ ratio;
- The flow is governed by the jet velocity and the kinectic viscosity;

Thank You!