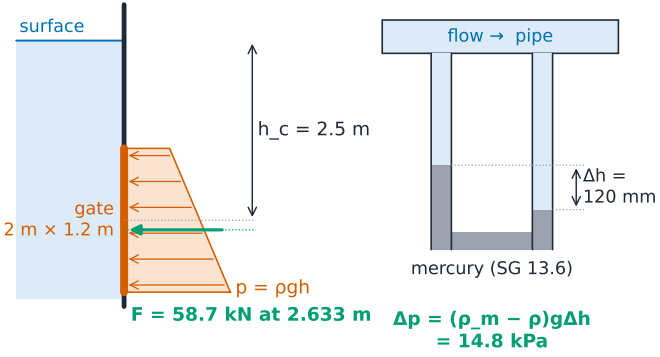
Fluid Mechanics

Curated undergraduate study track (not accredited, no external exam). Original explanations and practice only, following the reviewed course handout.

Fluids on the cooling-water loop

- The seventh course: how liquids and gases push on walls, carry momentum and lose energy, worked on the cooling-water loop the Course 6 shaft turns.
- Water at 20 °C: $\rho = 998$ kg/m^3, $\mu = 1.002 \times 10^{-3}$ Pa · s; air $\rho = 1.204$ kg/m^3; every number recomputed in the course suite.
- Unit 7.1 holds the fluid still; 7.2-7.3 let it move; 7.4 shrinks the problem; 7.5-7.6 pay for friction in pipes and around bodies.

Statics: pressure grows with depth



Gate 2 m $\times$ 1.2 m, top 1.5 m down: $F = \rho g h_c A = \mathbf{58.7}$ kN, acting at $y_{cp} = y_c + I_c/(y_c A) = \mathbf{2.633}$ m - below the centroid.

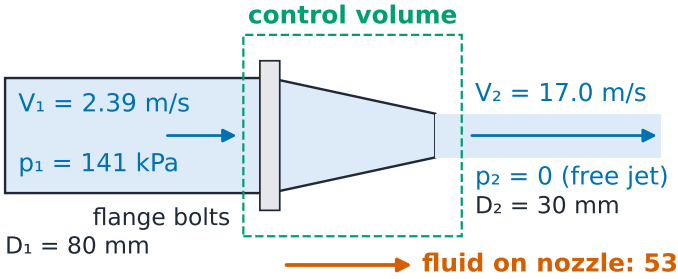
exercises.lol exercises.com.cn

Manometers and viscosity

1. **Manometer** Mercury (SG 13.6), $\Delta h = 120$ mm: $\Delta p = (\rho_m - \rho) g \Delta h = \mathbf{14.8}$ kPa. Using ρ_m alone overstates it by 8%.
2. **Viscosity** Plate at 2 m/s on a 0.5 mm oil film, $\mu = 0.29$ Pa · s: $\tau = \mu\, du/dy = \mathbf{1160}$ Pa.
3. **Kinematic** $\nu = \mu/\rho = 1.004 \times 10^{-6}$ m^2/s for water - the **viscosity** that enters every **Reynolds number**.

Control volume: the nozzle bolts

cut where you know p and V: inlet flange and free jet



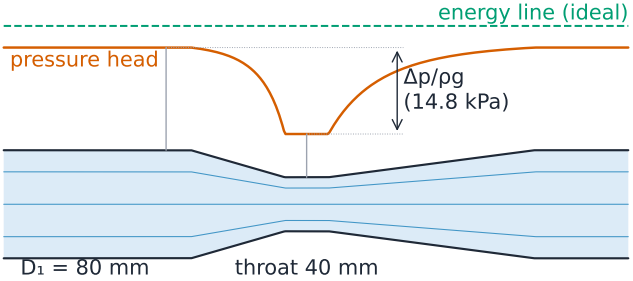
12 L/s from 80 mm into a 30 mm jet: $V_1 = \mathbf{2.39}$, $V_2 = \mathbf{17.0}$ m/s, $p_1 = \mathbf{141}$ kPa. $p_1 A_1 + F = \rho Q(V_2 - V_1)$: the fluid pushes the nozzle downstream with $\mathbf{534}$ N.

The bend and its thrust block

1. **Each direction** 90° bend, 80 mm, 150 kPa gauge, 12 L/s: $pA + \rho QV = 754.0 + 28.6 = \mathbf{782.6}$ N.
2. **Resultant** $\sqrt{2} \times 782.6 = \mathbf{1107}$ N at 45° - the thrust block's load.
3. **Lesson** At low speed pressure dominates momentum, so high-pressure lines need anchors even when the flow is slow.

Bernoulli: speed up, pressure down

Bernoulli along a streamline: speed up, pressure down

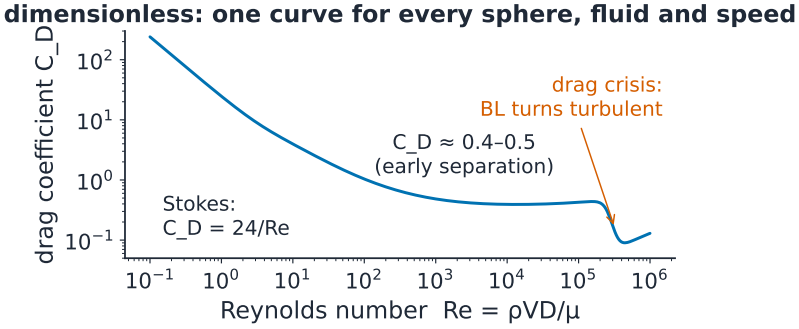


Venturi 80 → 40 mm ($\beta = 0.5$), $\Delta p = 14.8$ kPa: $Q_i = A_2\sqrt{2\Delta p/\rho(1-\beta^4)} =$ **7.07** L/s; with $C_d = 0.98$, $Q =$ **6.93** L/s.

The pitot tube and the assumptions

1. **Pitot** Air duct, 450 Pa between ports: $V = \sqrt{2\Delta p/\rho} = \sqrt{2 \times 450/1.204} = \mathbf{27.3}$ m/s.
2. **Validity** Mach 0.08, well under 0.3, so the air is effectively incompressible.
3. **Traps** Never across a pump or a lossy region; never drop $1 - \beta^4$; never $C_d = 1$ for an orifice.

Dimensional analysis: one curve for every sphere

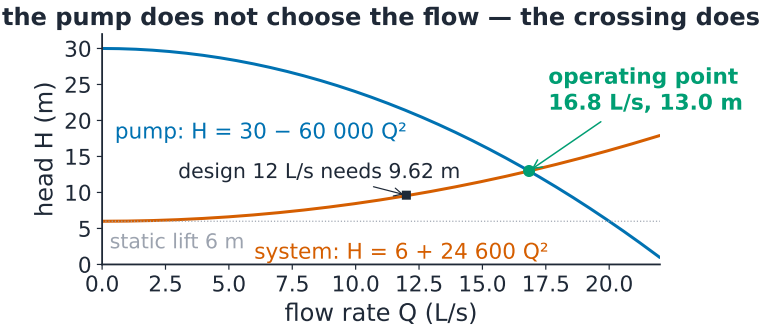


Five variables F, ρ, V, D, μ in three dimensions give two groups: $C_D = F/(\frac{1}{2}\rho V^2 A) = \phi(Re)$, with $Re = VD/\nu$.

The model test in a water tunnel

1. **Prototype** Pod 0.5 m at 20 m/s in air: $Re = 6.60 \times 10^5$.
2. **Model** Half scale in water: $V_m = 20 \times 2 \times (1.004 \times 10^{-6}/1.516 \times 10^{-5}) = \mathbf{2.65}$ m/s.
3. **Scale back** $F_m = 30$ N: $F_p = F_m(\rho_p/\rho_m)(V_p/V_m)^2(L_p/L_m)^2 = \mathbf{8.25}$ N.
4. **Pipe regime** Loop: $Re = 2.39 \times 0.08/1.004 \times 10^{-6} = \mathbf{1.90 \times 10^5}$ - turbulent.

Pipe flow: the pump meets the system



Pump $H = 30 - 60\,000Q^2$ against system $H = 6 + 24\,600Q^2$: they cross at $\mathbf{16.8}$ L/s and $\mathbf{13.0}$ m - 40% above the 12 L/s design.

Pricing the loop's losses

1. **Laminar oil** 20 mm line, $Re = 100$: $f = 64/Re = \mathbf{0.64}$, $h_f = \mathbf{4.08}$ m over 10 m ($\Delta p = \mathbf{34.8}$ kPa).
2. **Friction** Loop at 12 L/s: $\varepsilon/D = 5.63 \times 10^{-4}$, Colebrook $f = \mathbf{0.0192}$, $h_f = \mathbf{2.79}$ m.
3. **Fittings** $\sum K = 2.85$: $h_m = \mathbf{0.83}$ m; with 6 m lift the system needs $\mathbf{9.62}$ m.
4. **Power** At the operating point $\rho g Q H = \mathbf{2.14}$ kW; at 70% the shaft needs $\mathbf{3.06}$ kW, inside Course 6's 5.65 kW.

External flow: the boundary layer

the no-slip layer thickens downstream: δ = 5x/√Re_x (laminar)

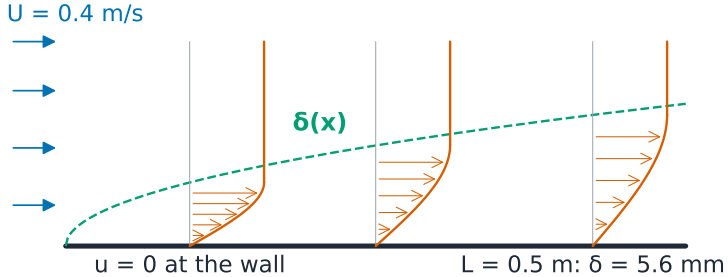


Plate 0.5 m in water at 0.4 m/s: $Re_L = \mathbf{1.99 \times 10^5}$, laminar; $\delta = 5x/\sqrt{Re_x} = \mathbf{5.6}$ mm, $C_f = 1.328/\sqrt{Re_L} = \mathbf{0.00298}$.

Drag on the vent pipe

1. **Plate drag** One side: $0.5 \times 998 \times 0.16 \times 0.00298 \times 0.15 = \mathbf{0.036}$ N; a turbulent layer would more than double it.
2. **Cylinder** Vent pipe $D = 0.1$ m, 3 m tall, 15 m/s wind: $Re = \mathbf{9.89} \times \mathbf{10^4}$, $C_D \approx 1.2$.
3. **Load** $F = 1.2 \times \frac{1}{2} \times 1.204 \times 225 \times 0.3 = \mathbf{48.8}$ N; base moment $\mathbf{73.1}$ N $\cdot$ m.

Check yourself

- The gate and the manometer? (58.7 kN at 2.633 m; 14.8 kPa.)
- The nozzle, the bend, the meters? (534 N; 1107 N; 6.93 L/s; 27.3 m/s.)
- The model and the loop? (2.65 m/s, 8.25 N; 16.8 L/s at 13.0 m, 3.06 kW shaft.)
- The plate and the pipe? (5.6 mm, $C_f = 0.00298$; 48.8 N, 73.1 N $\cdot$ m.)