

INSTRUCTIONS:

Calculator is allowed. Show all work. Even for the short questions, write down the formulas and the substitutions. State any simplifying assumptions (e.g. steady flow, incompressible flow, etc.).

Unless stated otherwise, the water density is 1000 kg/m^3 and dynamic viscosity is $1000 \cdot 10^{-6} \text{ kg/ms}$.

You may answer questions in Finnish (*On sallittua vasta kysymyksiin myös suomeksi*).

1. (10 points) Answer the following questions shortly. You can use figures and illustrations.
 - (a) What is the physical meaning of viscosity and how does it influence the flow of a Newtonian fluid?
 - (b) Define hydrostatic pressure and write the formula that relates it to depth in a fluid of constant density.
 - (c) State the difference between laminar and turbulent flow. Mention the typical Reynolds-number range for each regime in a pipe.
 - (d) Explain the continuity equation for incompressible flow and why it applies to a pipe-system with varying diameters.
 - (e) What is the Bernoulli equation (do not write me the equation, but shortly explain how it can be used and what for) and under which assumptions (list at least three) is it valid?
2. (10 points) Short calculations
 - (a) A water jet exits a nozzle of diameter 20 mm with a volumetric flow of 2000 litres/min. Determine the jet velocity.
 - (b) Water flows in a horizontal pipe. The pressure drop between two points is 2 kPa. The pipe diameter is 10 mm, and length is 30 m. Find the average velocity assuming laminar flow ($f = \frac{64}{\text{Re}}$)
 - (c) A tank contains 1 cubic metre of water. The inlet flow is 5 kg/s and the outflow is 3 kg/s. How long until there is 3 cubic metres of water in the tank?
 - (d) A fluid with a density of 900 kg/m^3 flows through a pipe with a mass flow rate of 4.5 kg/s. Pipe diameter is 40mm, what is the average flow velocity.
 - (e) The lecturer had his blood pressure measured and the readings was 80/120 mmHg (millimetres mercury). The density of mercury is 13350 kg/m^3 . What is the pressure difference of the two readings in *pascals*?
3. (5 points) A venturi is being used to measure the water flow velocity. The pipe diameter is 120mm and the throat diameter is 80mm. If the pressure difference is 20 kPa what is the flow velocity and Reynolds number in the pipe.
4. (5 points) Andrei is designing a hydrogen pipeline. He has already fixed the pipe diameter to be 1.2 m and it can be considered to be hydrodynamically smooth. The hydrogen mass flow in the pipe is 90

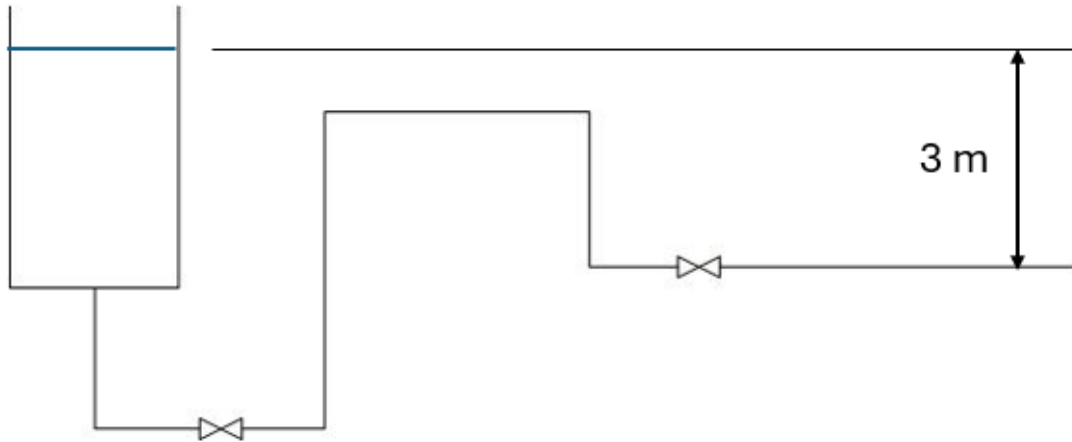
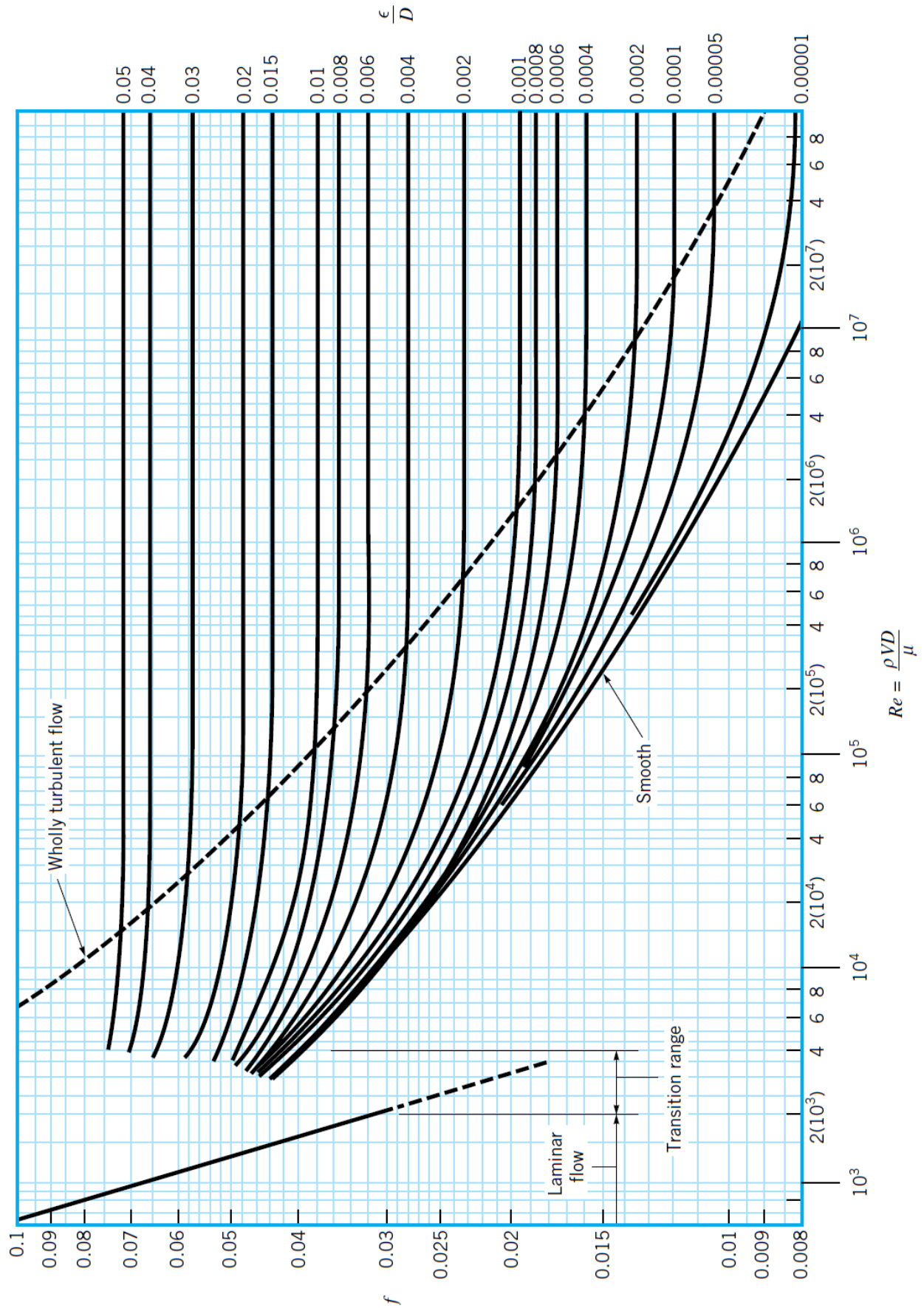


Figure 1: A flow system

kg/s. The hydrogen pressure after the first compressor station is 90 bars. The hydrogen pressure must not be less than 50 bar before the next compressor station. What is the maximum distance between the compressor stations? The density is 5 kg/m^3 , and the dynamic viscosity $9.6 \cdot 10^{-6} \text{ kg/ms}$. You can ignore the minor losses.

5. (10 points) Sea water ($\rho = 1020 \text{ kg/m}^3$, $\mu = 1.1 \cdot 10^{-3} \text{ kg/ms}$) must be pumped from sea level to a cooling tower, located 12 metres above the pump. The connecting pipe length is 250 m, and the pipe inner diameter is 90 mm. The pipe roughness is 0.15 mm. The design flow rate is 69 kg/s. Calculate the Reynolds number and **total pressure increase** the pump must create (hydrostatic + friction). If the flow and height of the tower can not be changed, how can we reduce the required total pressure increase?
6. (10 points) Water is (density 1000 kg/m^3 , dynamic viscosity $1000 \cdot 10^{-6} \text{ kg/ms}$) flowing in the system in Fig. 1. The total pipe length is 20 metres, pipe diameter is 50 mm, and the surface roughness is 0.002 mm. The water surface level in the tank is 3 m higher than the pipe outlet. The loss coefficients are 0.5 for the inlet, 0.7 per bend, and 7 per valve. Calculate the mass flow in the pipe.



Reynolds number:

$$\text{Re} = \frac{\rho w D}{\mu}$$

Hydraulic diameter:

$$D_h = \frac{4A}{P}$$

Shear stress:

$$\tau = \mu \frac{du}{dy}$$

Kinematic and dynamic viscosity:

$$\nu = \frac{\mu}{\rho}$$

Ideal gas equation of state:

$$\frac{p}{\rho} = R_i T$$

Pressure force:

$$F = pA$$

Hydrostatic pressure:

$$\Delta p = \rho g \Delta h$$

Mass flow:

$$q_m = \int \rho (\vec{w} \cdot \vec{n}) dA$$

1-D:

$$q_m = \rho w A$$

Volume flow (1D):

$$q_v = wA$$

Conservation of mass:

$$\frac{d}{dt} \int \rho dV + \int \rho (\vec{w} \cdot \vec{n}) dA = 0$$

Bernoulli equation:

$$p + \frac{1}{2} \rho w^2 + \rho g h = \text{CONSTANT}$$

or

$$p_1 + \frac{1}{2} \rho w_1^2 + \rho g h_1 = p_2 + \frac{1}{2} \rho w_2^2 + \rho g h_2$$

Pressure loss:

$$\Delta p_h = \left(f \frac{L}{d} + \sum K \right) \frac{1}{2} \rho w^2$$

Bernoulli equation with a pressure loss:

$$p_1 + \frac{1}{2} \rho w_1^2 + \rho g h_1 = p_4 + \frac{1}{2} \rho w_4^2 + \rho g h_4 + \Delta p_{\text{loss}}$$

Linear momentum equation (steady):

$$\sum F = q_m (w_2 - w_1)$$

Ideal gas EOS:

$$\frac{p}{\rho} = R_i T$$