EXAM PTP1 – RUG
Friday 12/7/2019

Maximum # points for each question are indicated for every exercise

Grade= 1+ # points/10

Write on the first page:

1) Your name
2) Your student number

Write on every following page your student number

Don't forget to write the dimensions in your answers (and of course dimensionless numbers have no dimensions!!!)

Good luck, FP

Be aware:

1) Exercise 5 is only meant for PTL students and 6 for PPT ones.
2) The text of the exam must be given back!

This exam was written and cross-reviewed by Prof. Dr. F.Picchioni, Dr. M.Cioffi, Prof. Dr. B. Jayawardhana. Dr. J. Yue made an overall review.

Question 1 #15

When a man is falling down with a parachute there are two forces acting on the man+parachute system: gravity and a friction force which is proportional to the velocity and whose direction is opposite to the falling direction. Assume that the proportionality constant k depends on the diameter of the open parachute.

a) Give the dimension of k.
b) Write a force balance for the man+parachute system. M is the mass of man+ parachute.
c) Use the force balance to derive an expression for the falling velocity as a function of the time. Give your answer in the form $v = a(1 - e^{-bt})$, where a and b are combinations of the parameters involved in this question.

Assume that the man's weight is 80 kg and that the parachute's weight is 10 kg. Suppose further that in order to make a safe impact on the ground, the impact velocity must be smaller than 20 km/h.

d) Calculate the required value for k. You may assume for the gravity acceleration a numerical value of 10 m/s^2.

Use dimension analysis to give a relationship for the falling velocity. In your answer, only dimensionless groups are allowed.

Question 2 #20

A spherical reactor is used for the continuous production of a chemical substance with the help of an exothermic chemical reaction (i.e. heat is generated during the reaction). For production requirements, the temperature of the liquid inside the reactor must be kept at 100 °C. The radius of the reactor is 5 m, the thickness of the reactor wall is 1 m. The exothermic reaction produces E = 400 J per second and per m^3. Because of security requirements the temperature at the external side of the wall must be 40°C.

a) Write a heat balance and calculate the thermal conductivity λ of the material used for the reactor wall.

The outside wall temperature is kept at 40 °C with the help of cooling water coming from a river nearby. The water flows around the reactor from left to right. The water has a temperature of 15 °C and because of environmental legislation may be heated up to maximum 20 °C.

b) Calculate the mass flowrate of river water required to achieve this cooling. Use **some** of the following parameters for water and **some** of the already mentioned parameters.

Density ρ = 1 kg/L; viscosity $\mu = 10^{-3}$ Pa.s; thermal conductivity λ = 0,6 $W \cdot m^{-1} \cdot K^{-1}$; $Pr = 7$; specific heat $c_p = 4{,}2 \cdot 10^3$ $J \cdot Kg^{-1} \cdot °C^{-1}$

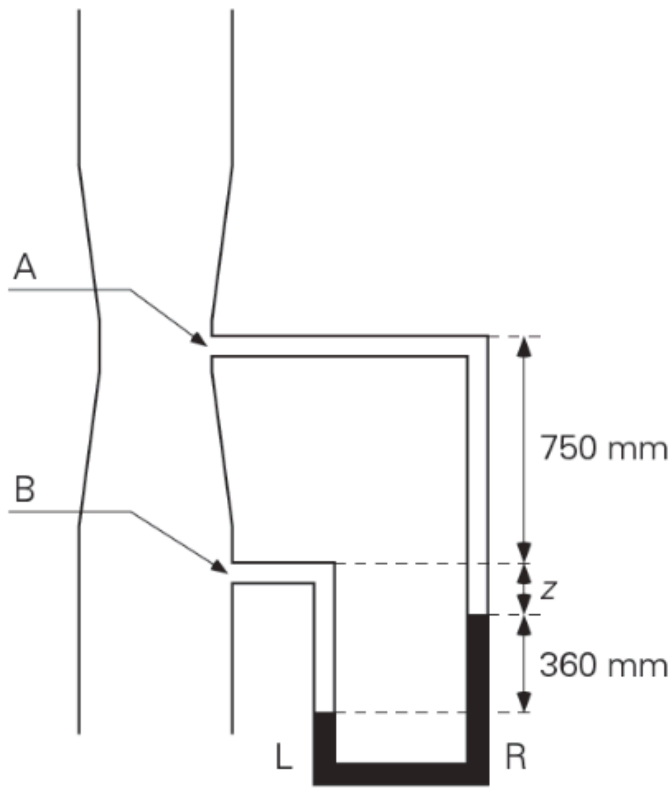
c) The cooling takes place as a consequence of forced convection. Calculate the heat transfer coefficient *h*.

Question 3 #20

Suppose we want to measure the volumetric water flow through a vertical pipe using a Venturi tube of 300 mm in diameter (at B) and with a smallest diameter of 150 mm (at A). The attached manometer shows a mercury level difference in the two legs (R and L) of 360 mm. The rest of the tubing is completely filled with water. Energy losses due to dissipation may be ignored. $\rho_{mercury}/\rho_{water}=13.6$ with ρ being the density of a given liquid.

Determine the volumetric flow.

Gravimetric constant g=9,8 m/s^2



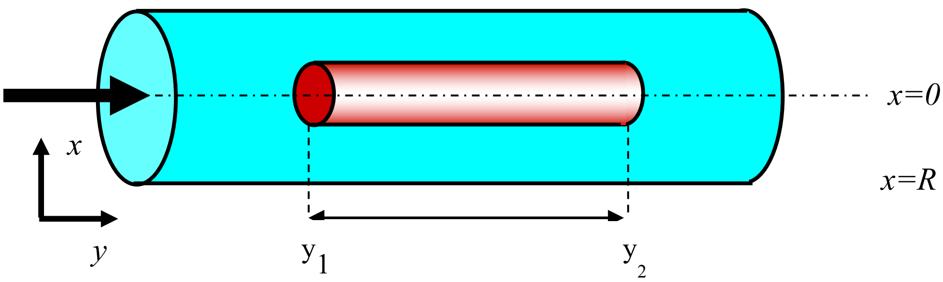
Question 4 #20

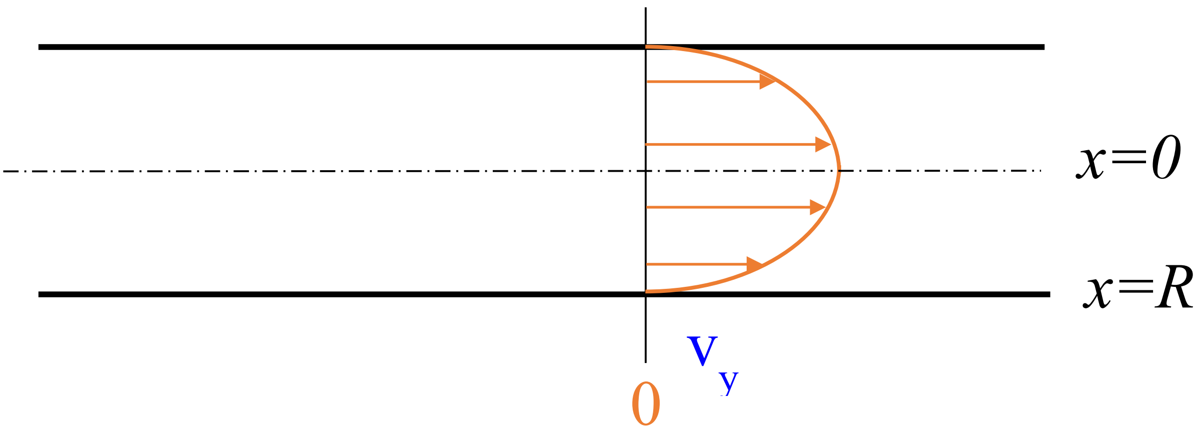
Water is flowing through a tube in laminar way as depicted in the figure below. In the tube a certain volume element is chosen of length Δy and radius R. Further it should be noted that the velocity profile is parabolic as depicted in the figure.

A) Derive a force balance on the volume element (small cylinder).

B) Provide an expression for the velocity in the y-direction

C) Derive a ratio over $\frac{v_y}{v_{y,max}}$





Question 5 (PTL, Teacher: Bayu Jayawardhana) 15 points

Useful formula

Fluid (linear) capacitor: $Q = C_f \frac{dP_{12}}{dt}$ where C_f is the capacitance, Q is the flow rate and P_{1r} is the pressure difference between P_1 and P_2, i.e., $P_{12} = P_1 - P_2$,

Fluid (linear) inertor: $P_{12} = I\frac{dQ}{dt}$ where I is the inertance, Q is the flow rate and P_{12} is the pressure difference between P_1 and P_2,

Fluid (linear) resistor: $P_{12} = RQ$ where R is the resistance, Q is the flow rate and P_{12} is the pressure difference between P_1 and P_2.

Consider a hydraulic system as shown in Figure 1 below.

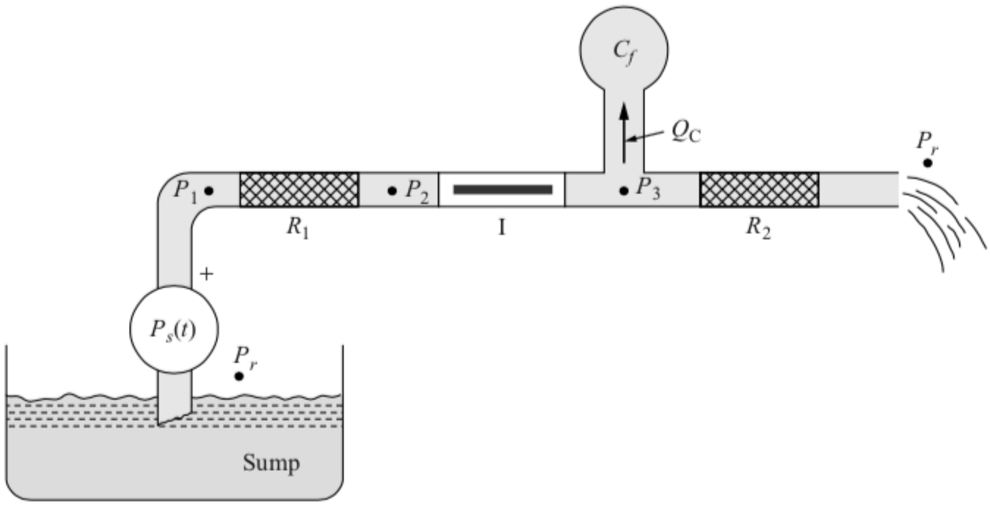


Figure 1. A hydraulic system comprising of a pressure source $P_s(t)$, two (linear) fluid resistors (with resistance of R_1 and R_2), a fluid inertor (with inertance I) and a fluid capacitor (with capacitance C_f).

In this system, there is an external pressure source $P_s(t)$ that are interconnected with two resistors, an inertor and a capacitor. The end-pipe is open ended and its outside pressure is equal to P_r. Assume that the resistors are linear with resistance of R_1 and R_2, respectively, the inertance is given by I and the capacitance is given by C_f.

A) Write down the state-space equations (or a set of first order differential equations) that describe the dynamics of the hydraulic system. (Grade: 8)

B) Suppose that $P_s(t) = 4$ for all t (i.e., it is kept constant), $R_1 = 2$, $R_2 = 1$, $I = 4$ and $C_f = 2$. Calculate the steady-state value of Q_1 and P_{3r} (where Q_1 is the volumetric flow that passes the inertor I) (Grade: 6)

C) Assume again that $R_1 = 2$, $R_2 = 1$, $I = 4$ and $C_f = 2$, while $P_s(t)$ becomes an external input (and not constant anymore). Compute the transfer function of the system with input P_s and output P_{3r}. (Grade: 6)

Question 6 (PPT specialization-Teacher F.Picchioni) 15 points

Useful formula

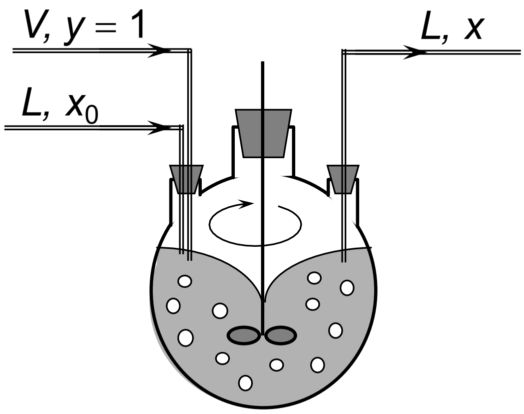
Flux (J) from an imaginary liquid phase always in equilibrium with a gas phase

$$J = k_{ox}\rho_x\left(x - x^*\right)$$

$$k_{ox} = \left[\frac{1}{k_x} + \frac{1}{mk_y}\right]^{-1}$$

with k_{ox} being the overall mass transfer coefficient, k_x the mass transfer coefficient for the liquid phase, k_y the mass transfer coefficient for the gas phase, ρ_x the density of the liquid phase, m the volumetric partition coefficient between the gas and liquid phases, x and x^* the molar fraction in the liquid and imaginary liquid phase respectively.

A liquid stream of benzene (L being the molar flow in mol/s and x the corresponding molar fraction) has to be saturated with carbon dioxide (CO_2). This is done in the equipment depicted below by using a stream of pure CO_2 (V being the molar stream and y the corresponding molar fraction). The liquid inside the flask can be considered as well-stirred.



Assume that the system is at non-equilibrium.

- **A.** Draw a schematic model for this system by specifying the phase in- and out-put as well as the kind of mixing for the liquid phase. **10 points**
- **B.** By defining an imaginary liquid phase always in equilibrium with the gas one, define an equation relating the molar fraction of CO_2 in benzene in the outgoing stream (x) as function of the volumetric stream of the liquid (Q_x). What is the molar concentration x at the outgoing stream if x_0=0, L=10^{-3} mol/s, ρ_x=8000 mol/m^3,

k_x=4*10^{-4} m/s. The total surface area (A) for the gas bubbles in the flask is 0.15 m^2. The molar partition coefficient for CO_2 between the gas and the liquid phase is 2.5*10^3. **10 points**