Q1

Short description (max 150 words): Explain the terms *manipulated variable*, *controlled variable* and *disturbance variable*.

Q2

Short description (max 75 words): In the context of controller design, what means the *derivative kick*? Which types of controllers it may affect?

Q3

Short description (max 75 words): What means *feedforward control*?

Q4

Essay (max 600 words): What are the working principles of analog and digital signals? How the use of digital signals has transformed the field of process control?

Q5

Short description (max 150 words): What is the difference between the *process gain* K_p, *controller gain* K_c, and *sensor gain* K_m?

Process control and automation (CHEM-C2140)
Exam, part 2: mathematical problems

April 6, 2020

Q6) The temperature inside the jacketed continuous process reactor (see Fig 1) is controlled by manipulating the volumetric flow rate of the cooling medium q_c. The cooling medium is assumed to remove heat from the tank at the rate Q that is linearly proportional to its volumetric flow rate q_c:

$$Q = kq_c$$

where k is a constant representing the effectiveness of the heat transfer (unit: [J/m^3]). The chemical process inside the tank generates heat at the rate of E_r (unit: [J/s]). However, this rate is not constant but may vary over time. The inlet flow temperature T_{in} is constant.

Derive a physics-based model for the temperature T in the tank as a function of

- volumetric inlet flow rate q_{in},
- volumetric flow rate of the cooling medium q_c,
- process fluid temperature at the inlet T_{in},
- mass of process fluid in the tank m,
- density of the process fluid ρ,
- heat generation rate of the reaction E_r,
- heat transfer constant k, and
- specific heat capacity of the process fluid c.

The process liquid mass m inside the reactor is held constant. The reactor is also well-mixed. State also other assumptions that are needed. Follow the steps of the systematic model development (discussed on Lectures 1 & 3).

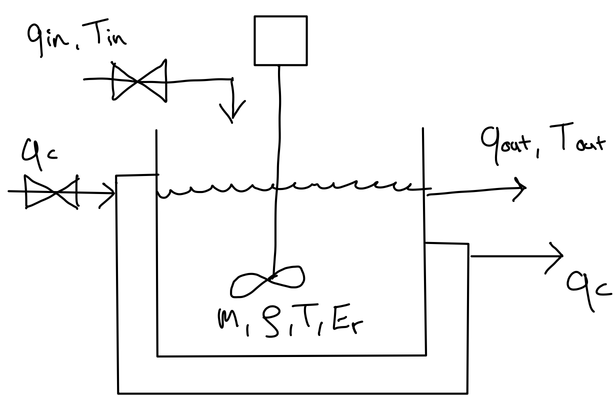

Figure 1: Jacketed continuous process reactor.

(8p)

Q7) Let us consider the differential equation

$$-4\frac{d^2y(t)}{dt^2} + 4\frac{dy(t)}{dt} - y(t) = 3$$

with initial conditions $y(0) = 0$, $y'(0) = \frac{3}{2}$. Solve the differential equation using the Laplace transform. In other words, express $y(t)$ as an algebraic equation that does not involve any derivatives of $y(t)$.

(6p)

Q8) Sketch by hand the ouput response $y(t)$ of the FOPDT model when the input variable $u(t)$ is that shown in Fig. 2. The FOPDT model has the process gain of $K_\mathrm{p} = -5$, time coefficient of $\tau_\mathrm{p} = 1$ s, and dead time of $\theta_\mathrm{p} = 2.5$ s. At $t = 0$ s, the output response is at a steady-state value of $y(0) = 50$. Make the sketch for the range of [0, 20] s.

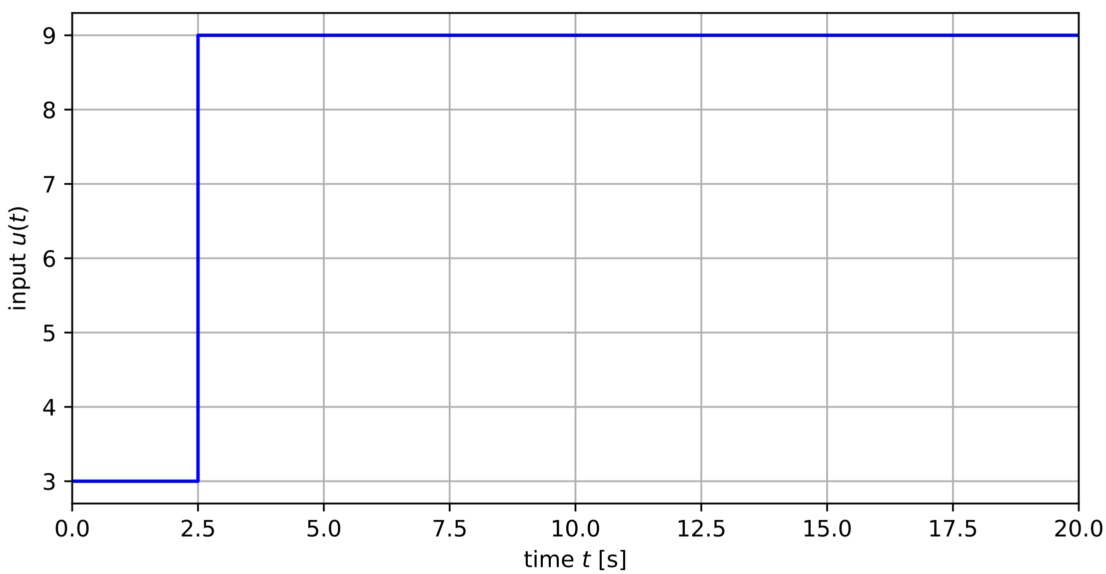

Figure 2: The input variable $u(t)$ during the time window $t \in [0, 20]$ s.

(3p)

Q9) Let us consider the liquid tank shown in Fig. 3. The volumetric outlet flow rate q_{out} from the tank is linearly proportional to the liquid level h in the tank

$$q_{\text{out}} = rh,$$

where r is a constant. The physics-based model for the tank level h is

$$\frac{dh}{dt} = \frac{1}{A}\left(q_{\text{in}} - rh\right),$$

where q_{in} is the volumetric inlet flow rate, ρ is the density of the liquid, and A is the cross-sectional area of the tank. At $t = 0$, the tank is empty. Therefore, the initial condition is: $h(0) = 0$.

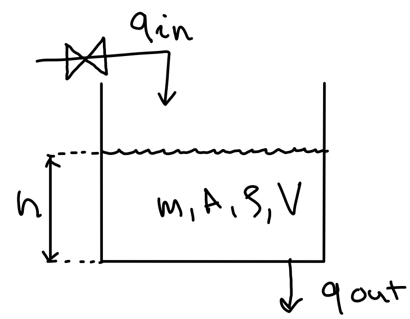

Figure 3: A liquid tank with a hole.

a) Derive the transfer function $G(s) = H(s)/Q_{\text{in}}(s)$ (in which $H(s)$ and $Q_{\text{in}}(s)$ are the liquid level and the volumetric inlet flow rate, respectively, in the Laplace domain) based on the physics-based model.
b) Determine the process gain K_c based on the transfer function.

(4p)