Surname **Name** **Student's code.:**

There is no need
Indeed, it is NOT allowed to use a programmable calculator!

Section 1: TRUE/FALSE QUIZZES

1. A process with a transfer function having a positive gain is said to be **direct acting.**

   true ☐ false ☐

2. In a transfer function G(s), the variable s belongs to the set of real numbers.

   true ☐ false ☐

3. A linear dynamical system is BIBO stable if its transfer function has at least one pole with a negative real part.

   true ☐ false ☐

4. A self-regulating first order dynamical system is in a stable steady state P for $t<0$.If in $t=0$ an impulse perturbation is applied, the regime approached by this system after it is still P

   true ☐ false ☐

Section 2: QUIZZES

1. The offset is:

a. ☐ $y_\infty - y_{SP}(t)$
b. ☐ $y_{SP}(t) - y_\infty$
c. ☐ $y_\infty - y_m(t)$
d. ☐ always positive

2. The Laplace transform cannot be used to solve

a. ☐ second order differential equations
b. ☐ linear or linearised differential equations
c. ☐ nonlinear differential equations
d. ☐ higher-order linear differential equations

5. Which of the following "parameters" is not included in the 2nd order system law?

a. ☐ Process gain
b. ☐ Dead time
c. ☐ Natural oscillation period
d. ☐ Damping factor

Section 3: REFERENCE DYNAMIC MODELS

3.1. Response of a dynamic model

A chemical reaction is taking place in a tank, and the concentration of a reactant is being monitored by a concentration analyzer. The relationship between the measured concentration $C'_m(s)$ and the actual concentration $C'(s)$ is given by the following transfer function (in deviation variable form):

$$\frac{C'_m(s)}{C'(s)} = \frac{1}{s+1}$$

The system is at its steady-state (SS) value, with actual and measured concentration of 2 mol/L: C_{ss}= $C_{m_{ss}}$= 2 mol/L. A warning light on the analyzer turns on whenever the measured concentration drops below 1.5 mol/L. Suppose that at time t = 0 min, the concentration of the reactant in the tank begins to exponentially decrease, $C(t) = 2\exp\left(-\frac{t[min]}{10}\right)$, where C has units of mol/L and t has units of minutes.

1. Which type of reference dynamic model is represented by the above transfer function?
2. How much is the steady-state gain?
3. How much is the time constant?
4. Is the process affected by dead time? If so, how much is the time delay?
5. Write the forcing function $C(t)$ in terms of deviation variable(s) $C'(t)$ in the time domain.
6. Transport the forcing function $C'(t)$ in the Laplace domain ($\hat{C}(s)$).
7. Obtain the expression, in the Laplace domain, of the measured concentration $\hat{C}_m(s)$.
8. Obtain the expression of the time evolution of the measured concentration in terms of deviation variable C'_m(t)
9. At what time, with the approximation of ±0.5 min, will the warning light turn on?

Hints:

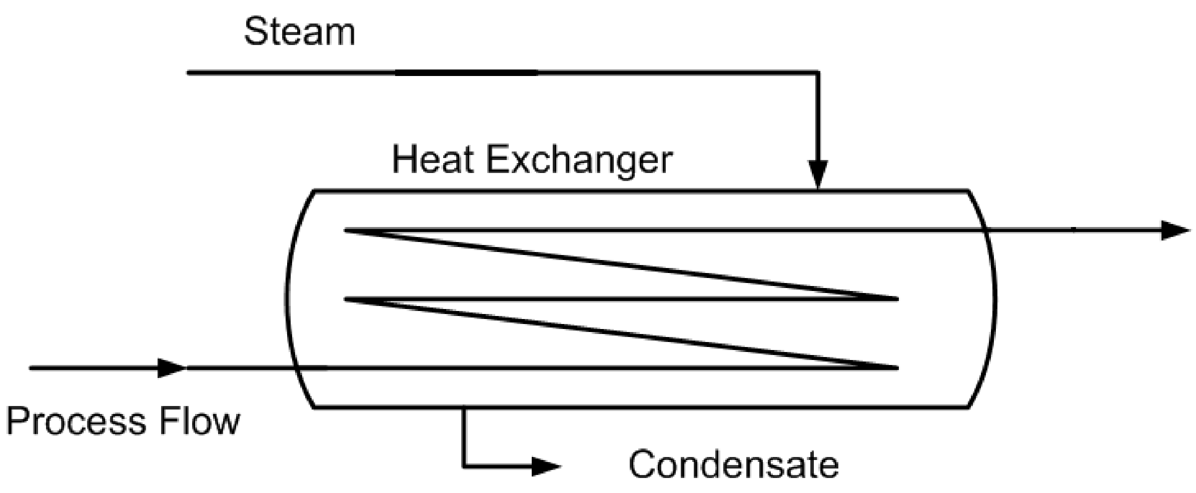
- The following table can be used to approximate the exponential decay function

t	*exp(-t)*
0	1.00
0.25	0.78
0.5	0.61
0.75	0.47
1	0.37
1.5	0.22
2	0.14
2.5	0.08
3	0.05
3.5	0.03
4	0.02
4.5	0.01

Section 4: CONTROL AND MONITORING

4.1. The feedback control

A feedback control has to be performed on a heat exchanger (see the figure) to assure that the process flow is correctly preheated before being further processed.
The heat is provided by the condensation of saturated steam, whose flow rate is **the manipulated variable** of the feedback control loop**.**



1. propose, on the same drawing, **the P&ID**
2. select the **controlled variable**
3. select the **disturbance variable/s** (if any)
4. draw the **closed loop block diagram** for this particular process control

Among the various process **block components** (tank, valves, motor, etc.) individuate on the P&ID (sketched as an answer to the above question 1.) the characteristic **components** of automatic control present in this process:

5. select the **sensor/measuring device**
6. select the **comparator**
7. select the **actuator**
8. select the **final control element**
9. what type of signal is used in the **control loop?**
10. what is the role of the tank in the **control loop system?**

Section 5: CONTROLLERS

A process must be controller and two types of controllers are available.

The following figures show the **closed loop** response (y(t)) of the process to a unit step change of the **set point (y_sp(t)** in **orange color**) along with the controller output (CO(t) in **yellow color**).

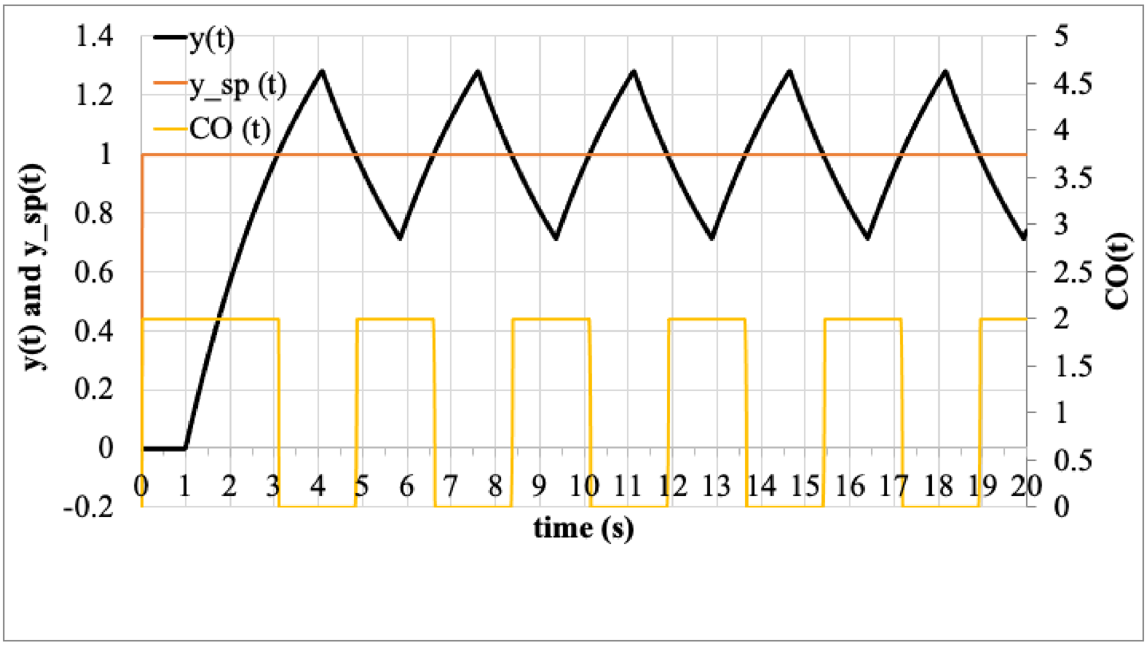


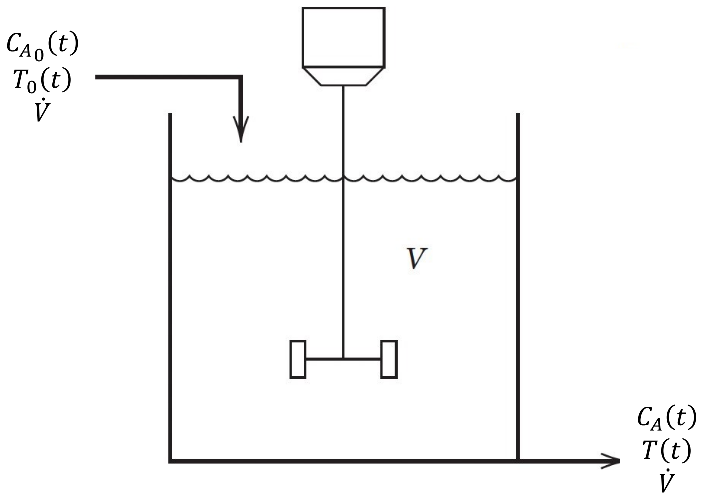
Figure 1. Controller type I

1. Is the process to be controller affected by time-delay?

2. Describe the type of controller in Figure 1 and describe its working principles, advantages, and disadvantages

Section 6: MATHEMATICAL MODELLING OF A LUMPED PARAMETER SYSTEM

An adiabatic CSTR, of volume V, is used to treat a liquid stream containing a toxic contaminant "A". Inside the reactor the contaminant A is converted in a non-hazardous chemical compound R, according to the following exothermic reaction:



$$A \rightarrow R$$

The rate equation is $(-r_A) = k$.

The volumetric flow rate $\dot{V}$ and the liquid density are constants, whereas, due to upstream processes both the inlet concentration $C_{A0}(t)$ and the inlet temperature $T_0(t)$ may vary in time.

Under the assumptions of constant kinetic constant k and heat of reaction ΔH_R:

1. write the **dynamical model** of the system;
2. write the **steady state** model of the system;
3. list **input**, **state**, **output** variables and the **parameters** of the model;
4. is the dynamical model a linear model? If not, **individuate and indicate the non-linear terms**.
5. **write the model in the Laplace domain;**
6. **obtain the transfer functions** describing the relation between the input and output variables;
7. **classify the obtained transfer functions** and individuate the parameters.

If the kinetic constant k, is not considered constant but is expressed with an Arrhenius law ($k = k_0 e^{\left(-\frac{E_a}{RT}\right)}$):

8. is the dynamical model still solvable with the Laplace transform? If so, how?
9. is there an impact of this choice on the transfer functions?