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. As General Guideline for Specifying the Controller Action (Direct or Reverse): the overall product of the gains for all of the components in the feedback control loop must be positive.

   true ☐ false ☐

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

   true ☐ false ☐

3. A linear dynamical system is BIBO marginally stable if its transfer function has a pole with a null real part with multiplicity higher than one.

   true ☐ false ☐

4. In a regulator problem the aim is to track the time varying set-point

   true ☐ false ☐

Section 2: QUIZZES

1. Which of the following ones is not an **actuator**?

a. ☐ hydraulic ram
b. ☐ centrifugal pump
c. ☐ *relay* controller
d. ☐ heating or cooling element

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

3. 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 thermometer has first-order dynamics with a time constant of 1 second, steady-state gain of 1. It is placed in a temperature bath at 120°F (T_{ext}). After the thermometer reaches steady state (T_{ext}=T_m=120°F), it is suddenly placed in a bath at 140 °F for $0 \leq t \leq 10$ s. Then T_{ext} is returned to the bath at 100 °F.

$$T_{ext}(t) = 120 + 20\,u(t) - 40\,u(t - 10)$$

Where $u(t)$ is the Heaviside step function.

1. Write the forcing function $T_{ext}(t)$ in terms of deviation variable(s) $T'_{ext}(t)$.
2. Write the forcing function $T'_{ext}(t)$ in the Laplace domain ($\hat{T}_{ext}(s)$).
3. Obtain the expression, in the Laplace domain, of the measured temperature $\hat{T}_m(s)$.
4. Obtain the expression of the time evolution of the measured temperature in terms of deviation variable T'_m(t)
5. Calculate the measured temperature at:
   a. t=0.5 s;
   b. t=10.5 s;
   c. t=15 s.

x	*exp(-x)*
0	1.00
0.25	0.78
0.5	0.60
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

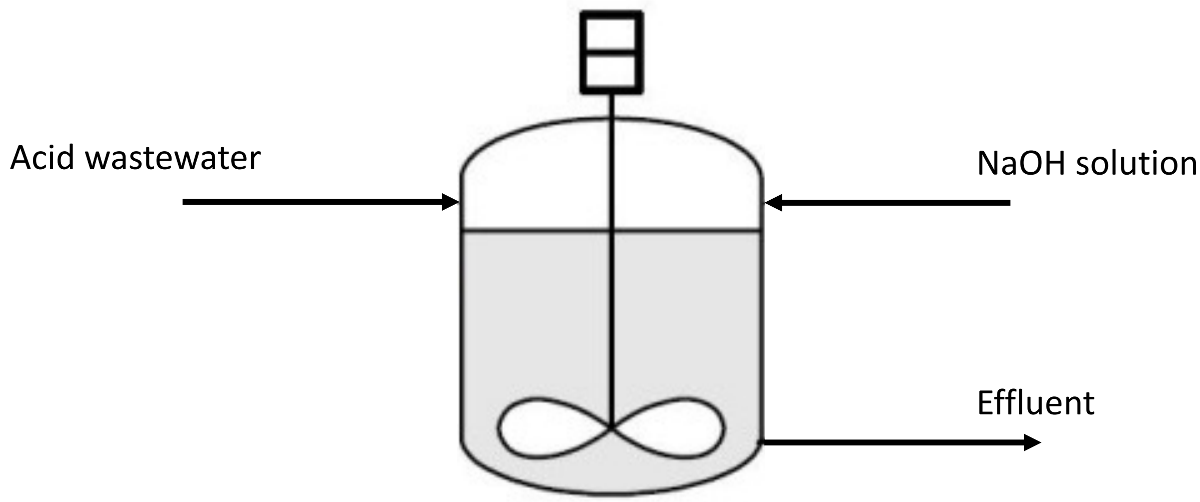
Hints:

- The $\mathcal{L}^{-1}\{e^{-t_d s} f(s)\} = u(t - t_d) f(t - t_d)$ where $u(t)$ is the Heaviside step function.
- The provided table can be used to approximate values of the exponential decay function:

Section 4: CONTROL AND MONITORING

4.1. The feedback control

A feedback control has to be performed on a CSTR (see the figure) used in a neutralization process. The base (Sodium Hydroxide, NaOH) is added to bring up the pH level and neutralize the acid wastewater in order to obtain a well-defined pH of the effluent (**controlled variable**).
The NaOH solution flow rate is **the manipulated variable** of the feedback control loop**.**



1. propose, on the same drawing, **the P&ID**
2. select the **disturbance variable/s** (if any)
3. 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:

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

Section 5: CONTROLLERS

5.1 Closed-loop step response and controller type

The following figures show the **closed loop** response (y(t) in **black color**) of the process to a unit step change of the **set point (y_sp(t)** in **orange color**) at t=0 s, along with the controller output (CO(t) in **blu dashed color**).

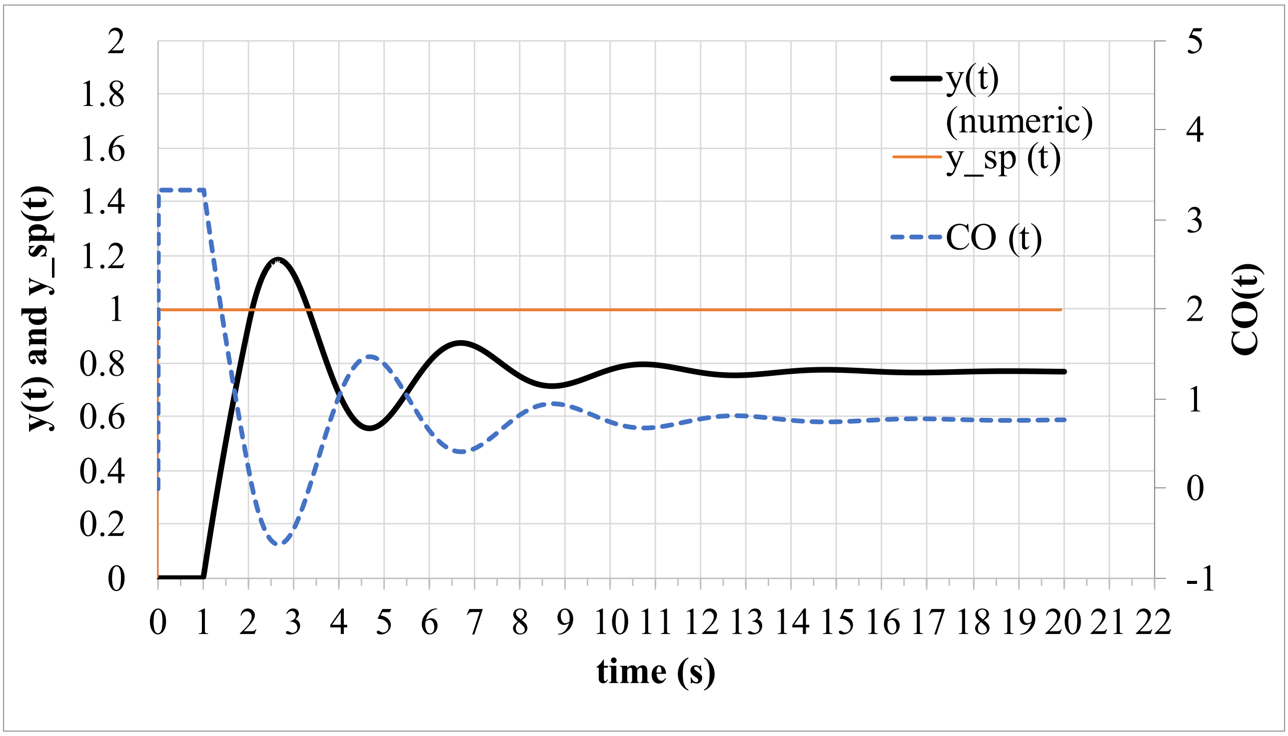


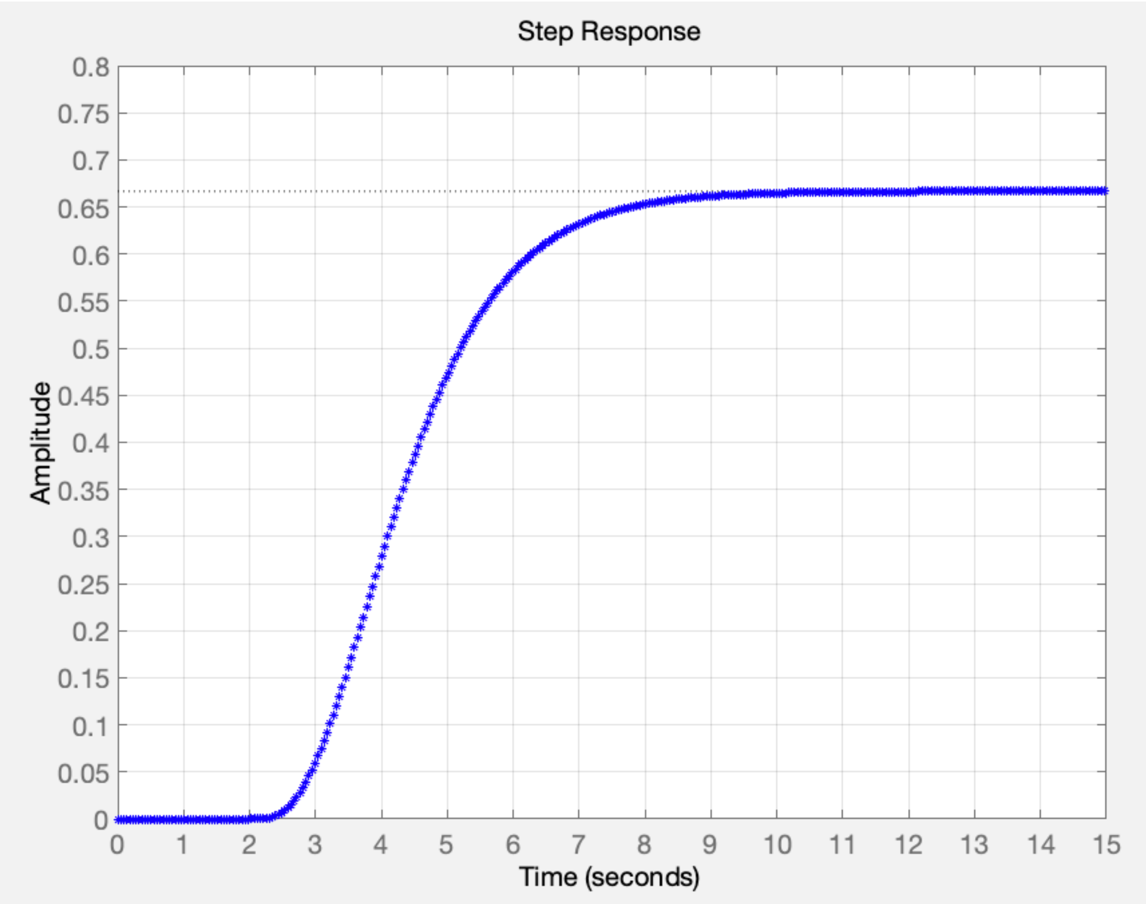
Figure 1. Controller type I

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

2. Describe the type of controller whose closed loop response is depicted in Figure 1, its working principle, advantages, and disadvantages

5.2 Open-loop PID Tuning with the "process reaction curve" method of Cohen and Coon

An unknown process at open loop is stimulated, at time 0 s, in its input by a **unit step function** and, in the open loop configuration, the response of the process variable (to be controlled at closed loop) is recorded (blue solid stars in the attached figure).



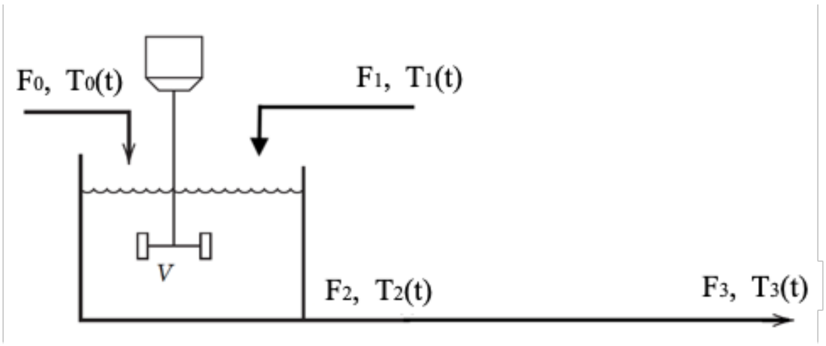
Approximate the open loop transfer function, whose step response is in the figure above, with a FOPDT transfer function.

1. Determine the process gain Kp
2. Determine the time constant τ_P
3. Determine the dead time t_d
4. Which type of **PID controller** tuning formula can be used?

Section 6: MATHEMATICAL MODELLING OF A LUMPED PARAMETER SYSTEM

A perfectly stirred, constant-volume tank has two input streams, both consisting of the same liquid. The temperature of both the inlet streams $T_0(t)$ and $T_1(t)$ can vary with time, whereas the volumetric flow rates F_0, F_1 and F_2 are constant.

The thermal-physical properties can be assumed constant, and the output line is relatively short, so that a negligible **time delay** for this line can be expected $\left(T_3(t) = T_2(t)\right)$.



You must

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.

A maintenance intervention on the plant modifies the path of the output line, increasing its length. Therefore, the assumption of negligible **time delay** t_d for the output line does not hold anymore and it is $\left(T_3(t) \neq T_2(t)\right)$.

In such a new situation you must:

8. write the **dynamical model** of the system;
9. **write the model in the Laplace domain**;
10. **obtain the transfer functions** describing the relation between the input and output variables.