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. The time constant τ_P of a first order system is the time interval which elapses before the step response reaches the 50 % of its final steady-state value

   true ☐ false ☐

2. A system is said to be BIBO stable if its output remains bounded for any bounded input.

   true ☐ false ☐

3. The steady-state error of a feedback-controlled system is the difference between the desired output and the actual output as time goes to infinity.

   true ☐ false ☐

4. A transfer function represents how a linear system modifies the Laplace transform of the input to produce the Laplace transform of the output.

   true ☐ false ☐

Section 2: QUIZZES

1. An industrial controller can be : (NB: mark only the wrong answer!)

a. ☐ "direct action"
b. ☐ "reverse action"
c. ☐ relay
d. ☐ FOPDT

2. The offset is:

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

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

a. ☐ Process gain
b. ☐ *overshoot*
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 mol/L. Suppose that at time t = 0 min, the concentration of the reactant in the tank begins to decrease, $C(t) = 2 - 0.5t$, where C has units of mol/L and t has units of minutes.

1. Which type of reference dynamic model is actually 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 delay? If so, how much is the time delay?
5. Write the forcing function $C(t)$ in terms of deviation variable(s) $C'^{(t)}$.
6. Write 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 ±1 min, will the warning light turn on?

Hints:

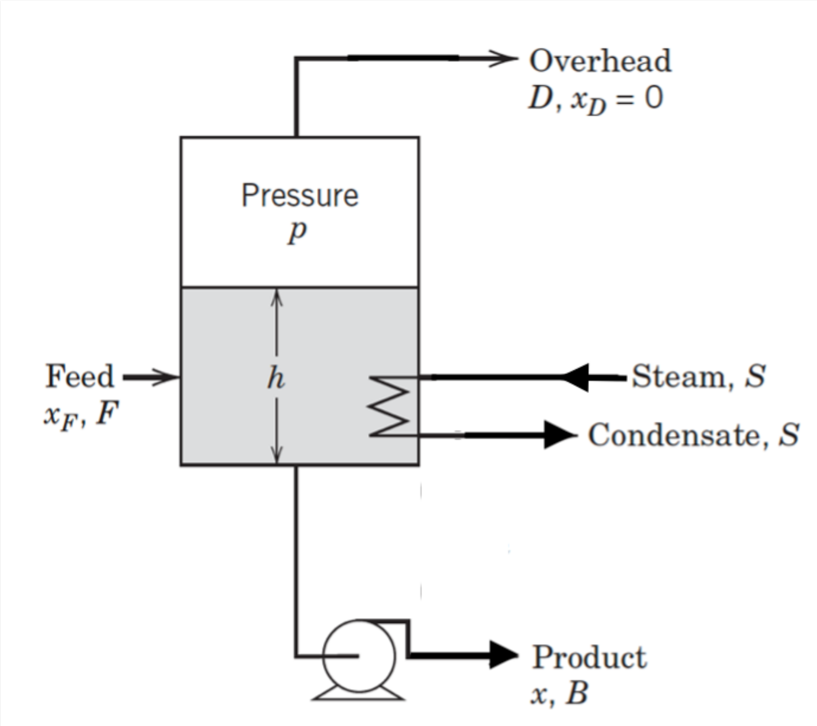
- The following table can be used to approximate the exponential decay function:

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 is to be performed of a continuous evaporator (see the figure) that concentrates a product from the mass fraction x_F in the feed to the larger one x_B in the bottom stream.
The manipulated variable is the flow rate of saturated steam S.



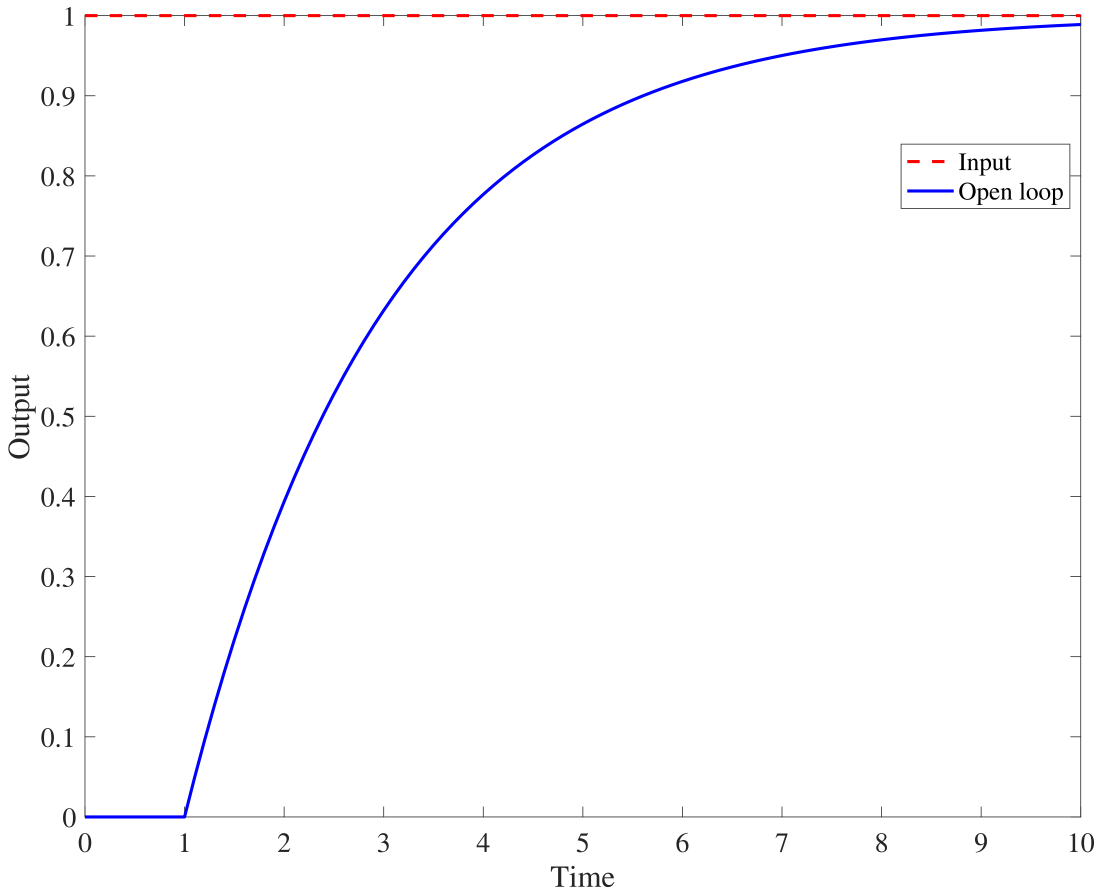
1. propose, on the same drawing, **the P&ID**
2. select the **controlled variable**
3. select the **disturbance variable** (if any)
4. draw the **block diagram for process control**

Among the various process **block components** (tank, valves, pump, etc.) individuate on the P&ID the characteristic variables 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

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

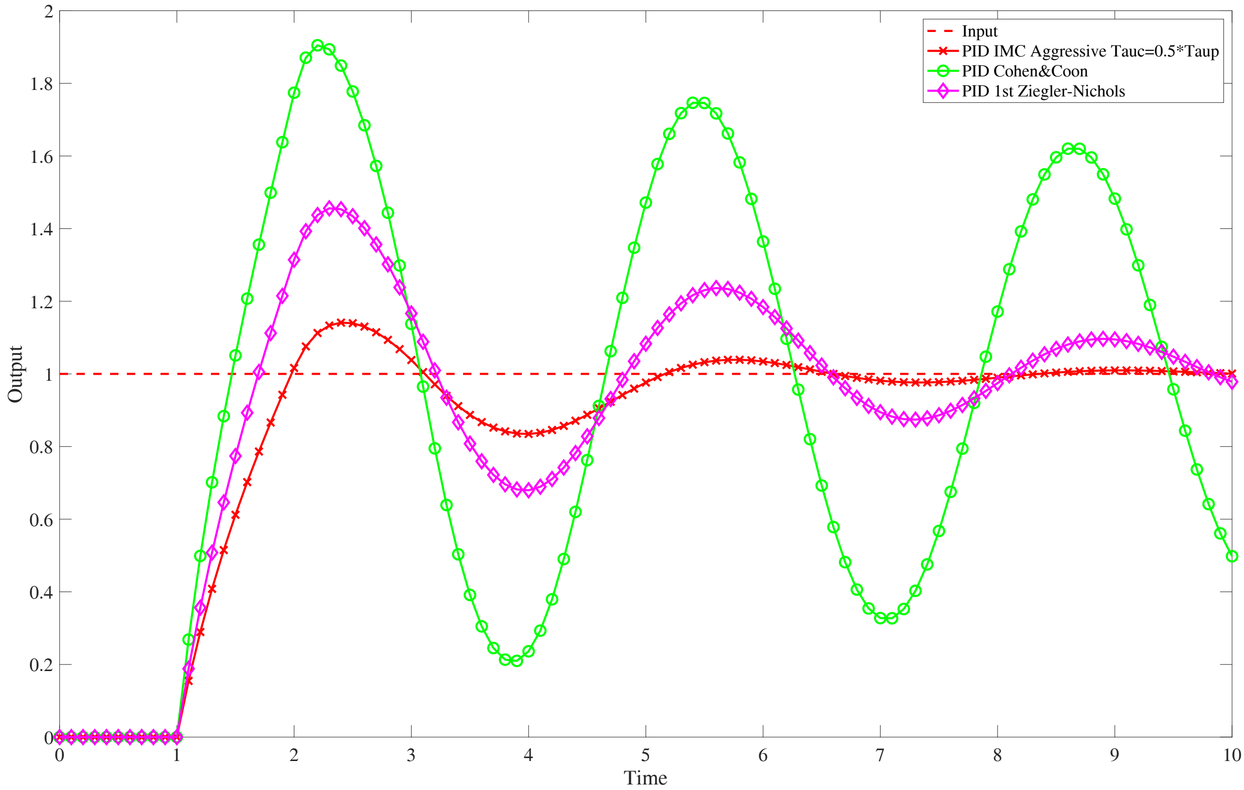


1. From the dynamic response determine the value of the **dead time** t_d

2. Obtain the transfer function of an FOPDT fitting model for which you may take K_p=1 and τ_p=2 s;

3. Describe **in a few words** the meaning of the FOPDT model

Different open loop tuning methods are used to find the optimal PID controller parameters and the resulting closed loop system responses are recorded and reported in the next attached figure.

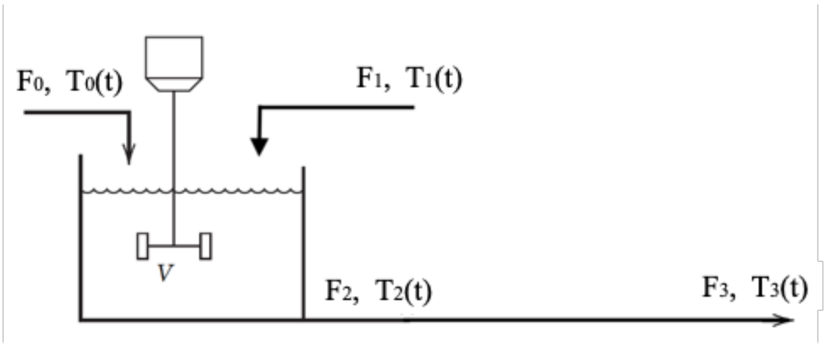


4. Which is the best, according to the provided figure, tuning algorithm?
(A qualitatively but detailed answer is required)

5. According to the best tuning algorithm proposed by you in 4), calculate the tuning parameters of the PID controller.

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 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.