**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 non-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 ☐

2. A dynamic system of the 3rd order always consists of 3 systems of 1st order in series

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

   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

The dynamic behavior of a **temperature sensor** can be approximated by a transfer function model:

$$G(s) = \frac{\widehat{T_m}(s)}{T(s)} = \frac{\frac{1}{2}}{\left(s + \frac{1}{2}\right)}$$

where $T_m$ and $T$ are the measured and actual temperatures. The system is at its steady-state (SS) value, with actual and measured temperature of 25°C: $T_{ss}$= $T_{m_{ss}}$= 25 °C.

Suppose that at time t = 0 min, the actual temperature begins vary according to the following time law:

$$T(t) = 25 + 25\left[1 - \exp\left(-\frac{t}{10}\right)\right]$$

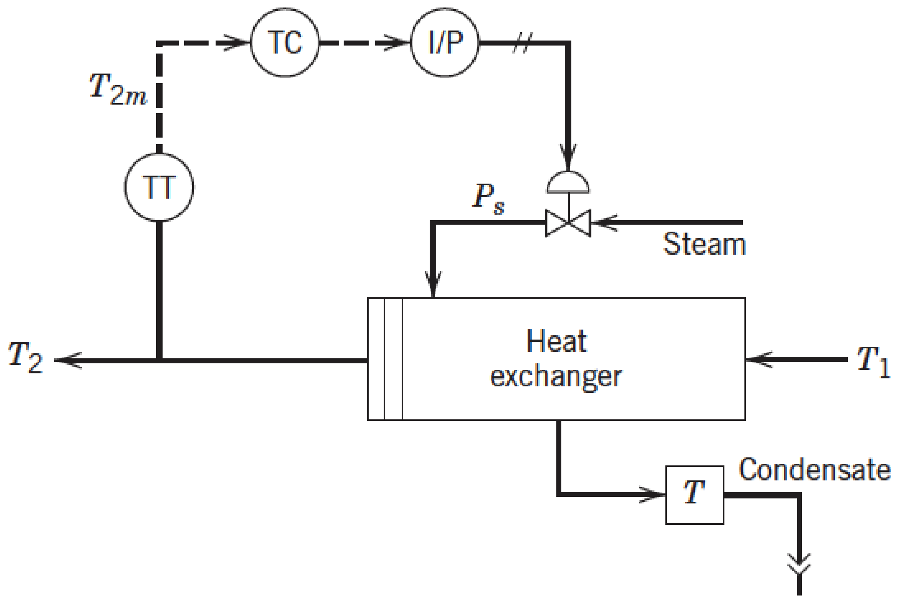
1. Write the forcing function $T(t)$ in terms of deviation variable(s) $T'(t)$.
2. Write the forcing function $T'(t)$ in the Laplace domain ($\widehat{T}(s)$).
3. Obtain the expression, in the Laplace domain, of the measured temperature $\widehat{T_m}(s)$.
4. Obtain the expression of the time evolution of the measured temperature in terms of deviation variable $T'_m(t)$.
5. At very long time (t→∞), what is the maximum variation in the measured temperature, $T_m(t)$?
6. At t=5 s, what is the temperature $T_m(t)$ measured by the thermometer $T_m(t)$?

| *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 |

# Section 4: CONTROL AND MONITORING

## 4.1. The feedback control

A process stream is heated using a shell and tube heat exchanger.




1. select the **controlled variable**
2. select the **manipulated variable**
3. select the **disturbance variable/s** (if any)
4. draw the **closed loop block diagram** for this particular process control

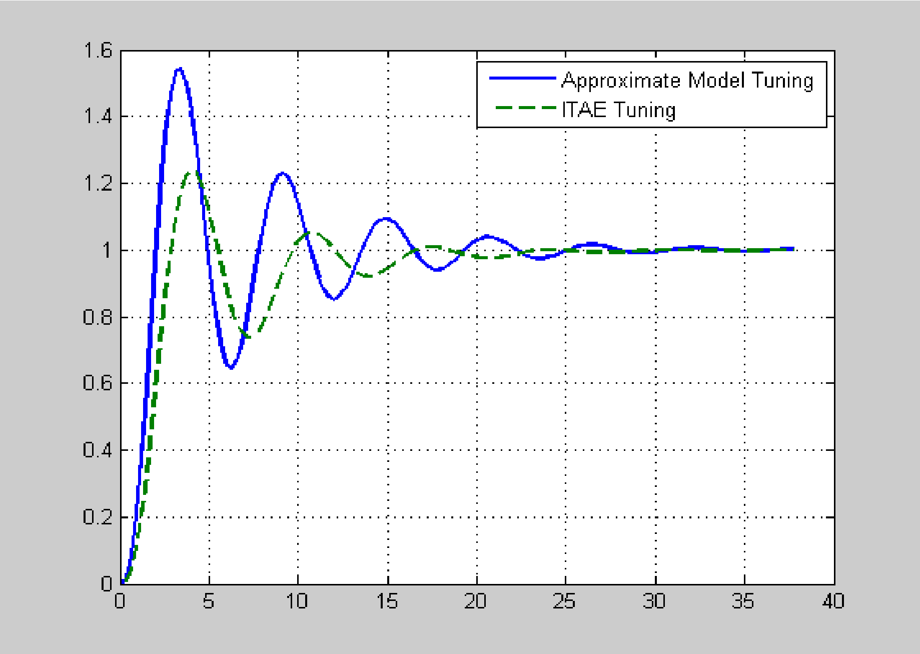
Among the various process **block components** (heat exchanger, valves, etc.) individuate on the P&ID (sketched as an answer to the above question 1.) the characteristic **components** of automatic control present in this process:

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 heat exchanger in the **control loop system?**

# Section 5: CONTROLLERS

## 5.1 Tuning the PID controller

A **PID** controller is subjected to a first *tuning* procedure (*Approximate Model tuning*) and used to control a dynamic system at **closed loop** for *set point tracking* (see the **dynamic response** with a continuous curve in fig.) following a *step* response.




Then, the same **PID** controller is subjected to an ITAE *tuning* procedure, and the dynamic system controlled by it at closed loop is again subjected to a *step* response in the *set point* (see the **dynamic response** with dashed curve in fig.).

a. What is the ITAE formula?

☐ $\int_0^\infty e^2 dt$ ☐ $\int_0^\infty |e| dt$ ☐ $\int_0^\infty t e^2 dt$ ☐ $\int_0^\infty t|e| dt$

b. Which one of the 2 **dynamic responses** is better (and why)?

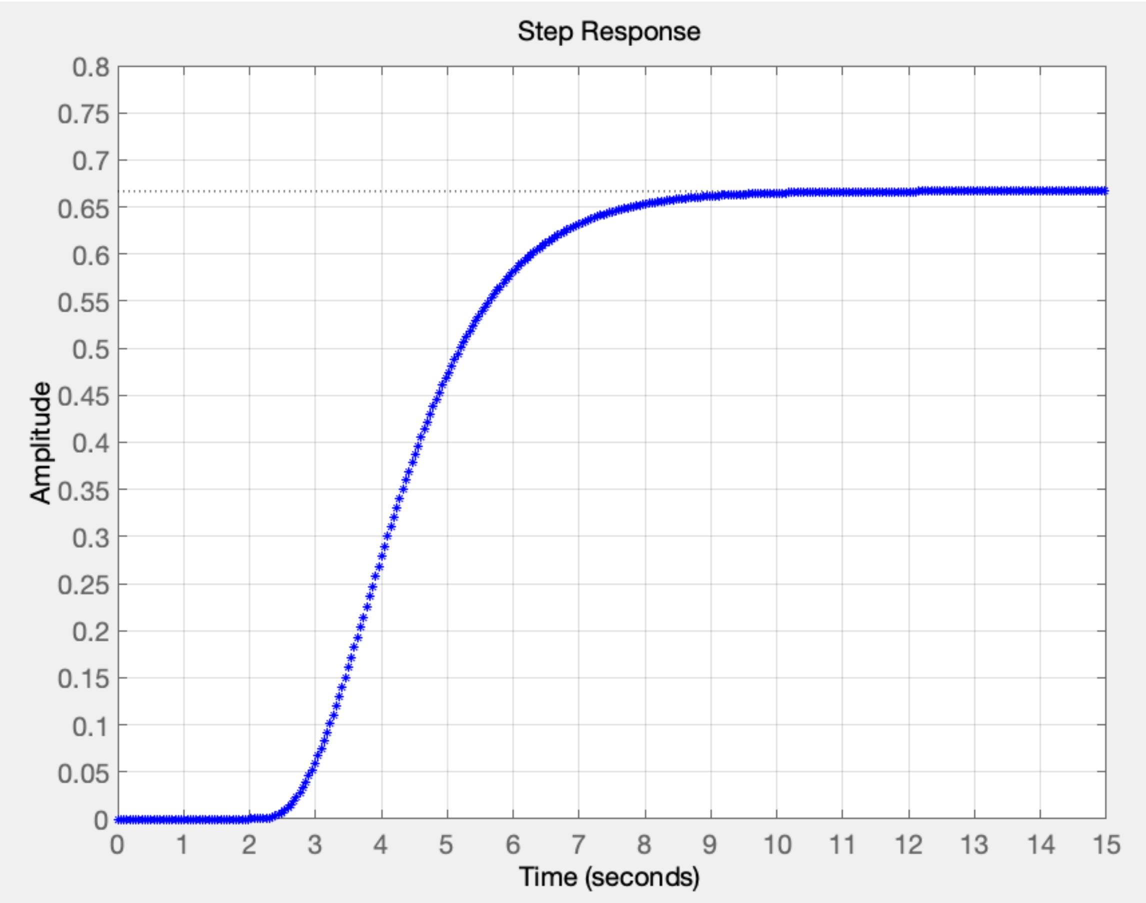
Type your answer here!

c. Discuss (qualitatively) the characteristics of **dynamic response** with ITAE *tuning*.

Type your answer here

## 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 (solid stars in the curve of 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 $K_p$

2. Determine the time constant $\tau_P$

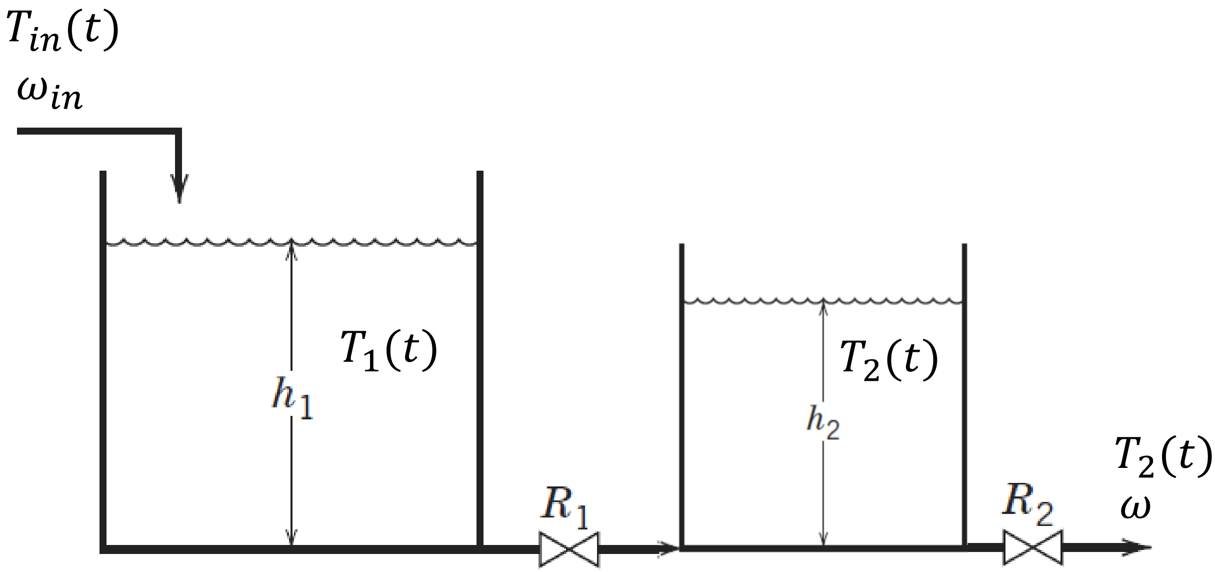
3. Determine the dead time $t_d$

4. Which type of PID controller tuning formula can be used?

## Section 6: MATHEMATICAL MODELLING OF A LUMPED PARAMETER SYSTEM

A sequence of well mixed tanks is depicted in the figure below.

The temperature of the inlet stream, $T_{in}(t)$, can vary in time, whereas all the mass flow rates are constant. The valves $R_1$ and $R_2$ assure a linear output flow rate with respect to the driving force, i.e., the effective level. The thermal-physical properties can be assumed constant.




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.

Given the inlet flow rate of 1 L/min, and the $R_1 = R_2 = 1$ min/dm$^2$:

8. What are the respective liquid levels, $h_1$ and $h_2$, in the two tanks?