Introduction to process control

DINAMICA E CONTROLLO DEI PROCESSI CHIMICI
A.A. 2019-2020
Corso di Laurea Magistrale in Ingegneria di Processo e dei Materiali

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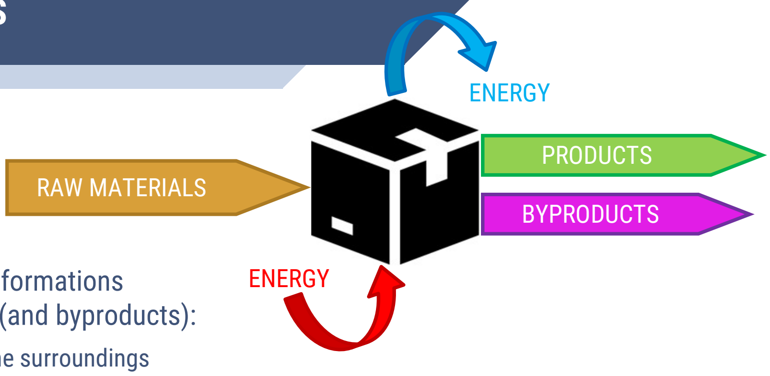
DEFINITION OF PROCESS



The process represents the set of transformations converting raw materials into products (and byproducts):

- Usually, energy is exchanged with the surroundings
- Sometimes the process involves energy exchange/transformation only

Often the term «process» is used to indicate both the processing operation and the processing equipment.

We will also assign the same meaning to the words «process» and «system».

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MOTIVATION OF PROCESS CONTROL

- Safety first
  - A process unit must operate far from conditions potentially harmful for:
    - The operators' lives
    - The surrounding environment (on both short and long terms)
    - Equipment integrity
- The profit motive
  - Meeting final product specifications
    - In «chemical» products, quality specifications are often related to such properties as concentration, viscosity, melt index, …
    - In other industrial sectors (e.g., food, pharma, …) product quality is defined by other properties, such as color, roughness, crispiness, hardness, …
  - Minimizing waste production
  - Minimizing environmental impact
  - Minimizing energy and/or raw materials use
  - Maximizing overall production rate

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THE CONTROL SYSTEM

- A process control system must perform two basic tasks
  - Monitoring the state of certain variables (*i.e.* controlled variables, CVs) that can provide indication of the current state of the system
  - Introducing changes in appropriate variables (*i.e.* manipulated variables, MVs) in order to improve the operation of the process
- Notice for Italian-speaking students
  - The word «controllo» must be intended with an active meaning
    - It does not simply refer to observation and supervision
    - Rather, it means intervention, action
  - For these reasons, the best italian translation for «control» would be «regolazione»

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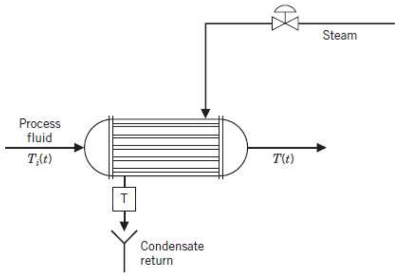
AN EXAMPLE: TEMPERATURE CONTROL

- Shell&Tube heat exchanger
  - Objective: heating the process fluid from $T_i(t)$ to $T(t) = T_{des}$ by condensing a utility stream (steam) within the exchanger
- Manual control:
  - If $T(t) < T_{des}$ slightly open the steam valve to transfer more energy to the process fluid
  - If $T(t) > T_{des}$ slightly close the steam valve to transfer less energy
- Problems!
  - An operator is needed to continuously observe $T(t)$, so as to achieve prompt intervention
  - Different operators would act with different rationales on the steam valve, making the exchanger operation inconsistent
  - Several operators would be required, because in a true process there might be hundreds of variables to be controlled simultaneously



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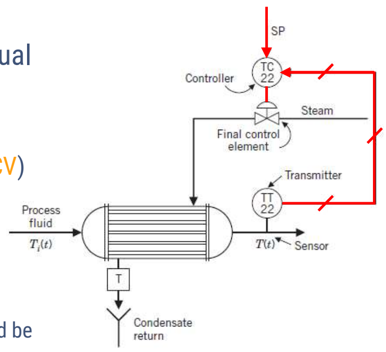
AN EXAMPLE: TEMPERATURE CONTROL

- One may think to automate the series of operations involved in the manual control of the exchanger
- Automatic control (closed loop):
  - A sensor (e.g., a thermocouple) <u>measures</u> the variable of interest (output; CV)
  - The sensor is physically connected to a transmitter (TT), which receives the signal and converts it so as to make it «strong» enough to be <u>transmitted</u> to the controller
  - The controller (TC) <u>compares</u> the signal to a reference one (set point, SP)
    - Depending on the result, it decides if, and by how much, the valve opening should be changed
    - It sends the corresponding signal to the valve
- This control strategy is called feedback control or «controllo in retroazione»



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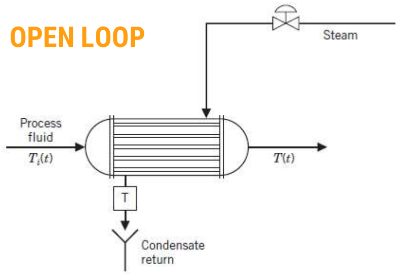
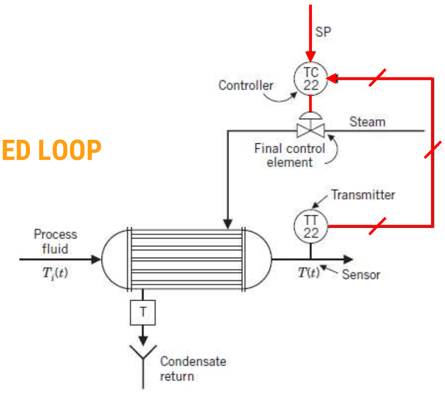
THE CONTROL LOOP

OPEN LOOP



CLOSED LOOP



- The basic elements of a control loop are:
  - Sensor-transmitter: the plant state is monitored
    - Sometimes called «primary» and «secondary» measurement elements
  - Controller: a decision is taken on the corrective action to be taken
    - The brain of the control system
  - Final control element: an action is taken
    - Usually a valve
    - Other examples: variable speed pump, electric motor, electric resistance, …
- For the controller to be effective, the action must have an effect on the measured variable

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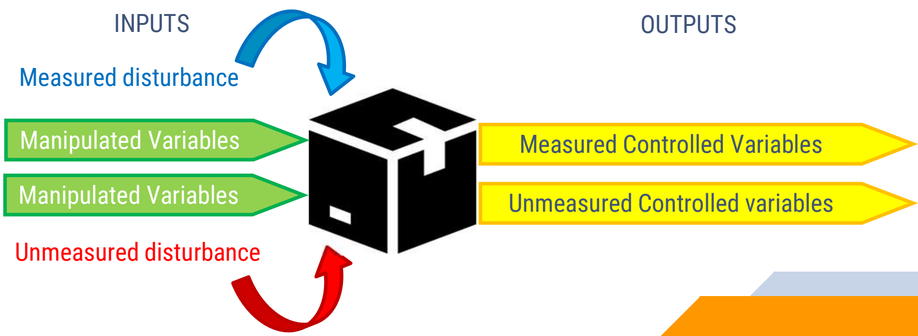
THE JARGON OF PROCESS DYNAMICS AND CONTROL

- Inputs: variable that independently «stimulate» a system; they can induce changes in the internal process conditions (states)
  - Manipulated variables (u, m, MVs): at the disposal of the control system
  - Disturbances (d, DVs): it is not possible to act on them
- Outputs: measurements (y), through which information on the internal of the system is obtained (e.g., temperature, level, viscosity, refraction index, …)
- States: minimum set of variables (x) that are necessary to completely describe the internal condition of a system (e.g., composition, holdup, enthalpy, …)



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THE TWO TYPICAL CONTROL PROBLEMS

- Regulatory control
  - The control system objective is to cancel the effect of disturbances, so as to keep the output to the constant value specified as the controller set-point
  - Disturbance rejection
- Servo control
  - The objective is to make the output track a set-point trajectory (hence, the set-point is time-varying)
  - Set-point tracking

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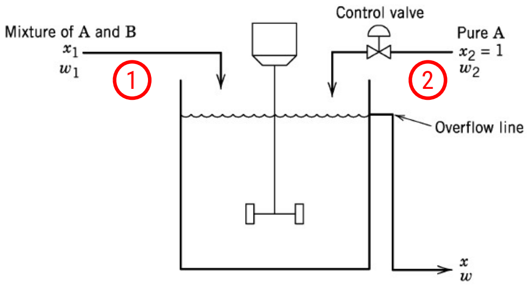
EXAMPLE: A MIXING PROCESS

- Objective:
  mixing the two inlet streams to obtain an output stream of assigned composition x_{sp} (weight fraction of A)
- Assumptions:
  - Constant volume
  - Constant mass flow w_1
  - Variable composition x_1
  - Stream (2) is pure A
  - Stream (2) flow w_2 can be manipulated



- If the nominal value of x_1 is $\bar{x}_1$, which nominal $\bar{w}_2$ is required to obtain the desired concentration x_{sp} in the outlet stream?

- Controlled variable (CV)? x
- Disturbance (DV)? x_1
- Manipulated variable (MV)? w_2

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EXAMPLE: A MIXING PROCESS

- Overall mass balance (nominal conditions)

$$\bar{w}_1 + \bar{w}_2 = \bar{w}$$

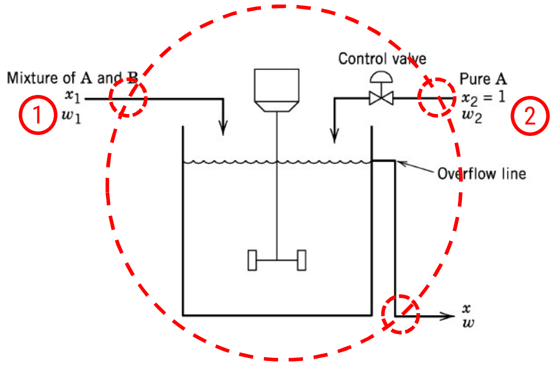
- Material balance on species A (nominal conditions)

$$\bar{w}_1\bar{x}_1 + \bar{w}_2\bar{x}_2 = \bar{w}\bar{x}$$

$$\Rightarrow \quad \bar{w}_2 = \bar{w}_1 \frac{x_{sp} - \bar{x}_1}{1 - x_{sp}}$$

This is the design equation at the nominal steady state

If the inlet concentration x_1 changes with time, how can one ensure that the outlet concentration x is always kept at the desired value x_{sp}?



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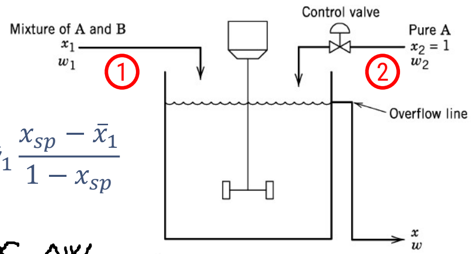
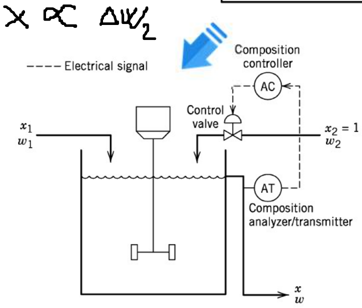
EXAMPLE: A MIXING PROCESS



- Method 1: Measure x and adjust w_2
  - The rationale
    - If x is too large, decrease w_2 and vice versa
  - This strategy can be implemented manually or automatically
    - Manual control vs automatic control
  - How much to decrease (or increase) w_2?
    - An idea: the more x differs from x_{sp}, the more one should change w_2
    - i.e., the w_2 variation is proportional to the distance of $x(t)$ from the set point

$$\bar{w}_2 = \bar{w}_1 \frac{x_{sp} - \bar{x}_1}{1 - x_{sp}}$$

$\Delta x \propto \Delta w_2$



FEEDBACK CONTROL

- Control law $\Rightarrow$ $w_2(t) = \bar{w}_2 + K_c[x_{sp} - x(t)]$

Kc: controller gain or «guadagno»
$[x_{sp} - x(t)]$: error

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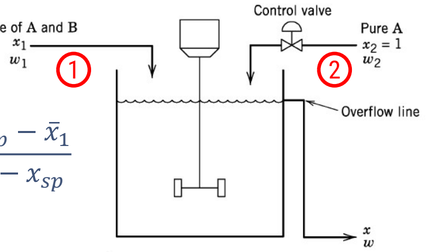
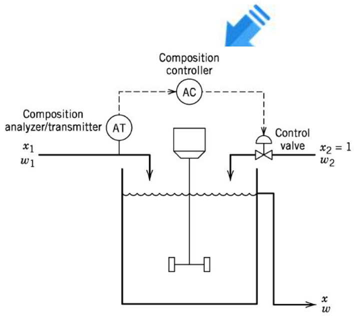
EXAMPLE: A MIXING PROCESS

- Method 2: Measure x_1 and adjust w_2
  - The rationale
    - If x_1 is greater than the nominal value, decrease w_2 and vice versa
  - How much to decrease (or increase) w_2?
    - An idea: using the steady state design equation under unsteady conditions

$$\overline{w}_2 = \overline{w}_1 \frac{x_{sp} - \overline{x}_1}{1 - x_{sp}}$$





FEEDFORWARD CONTROL

- Control Law

$$\Rightarrow \quad w_2(t) = \overline{w}_1 \frac{x_{sp} - x_1(t)}{1 - x_{sp}}$$

Is the control law truly effective?

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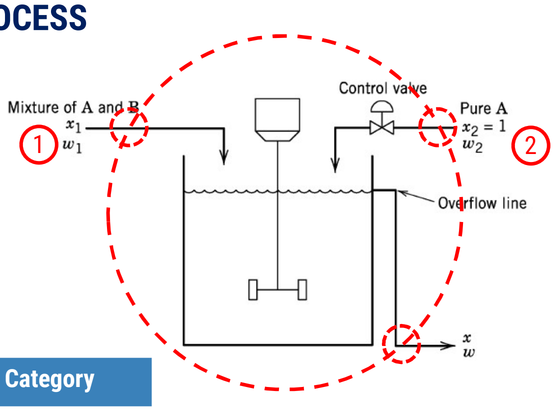
EXAMPLE: A MIXING PROCESS

- Method 3: Measure x_1 and x, and adjust w_2
- Method 4: Use a larger mixing tank



Method	Measured variable	Manipuated variable	Category
1	x	w_2	Feedback (FB)
2	x_1	w_2	Feedforward (FF)
3	x, x_1	w_2	FF+FB
4	-	-	Design change

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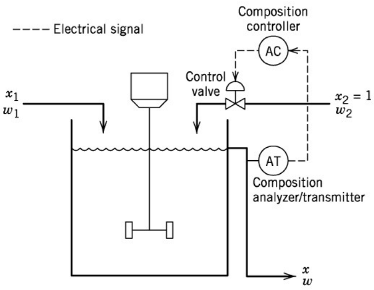
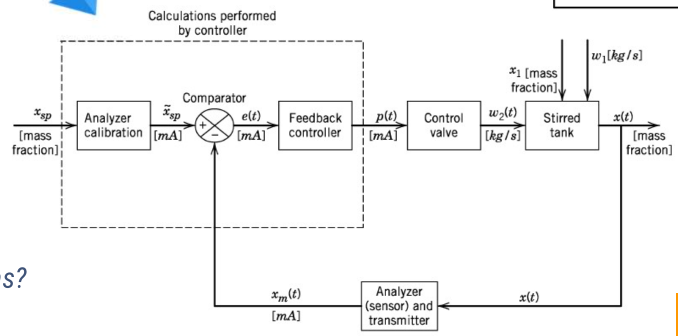
Block Diagram of FEEDBACK CONTROL

- The P&I diagram shows the physical connections between the control system elements



- The block diagram shows the logical connections and the information flux between the control system elements

- Each block can be described by a differential or an algebraic equation



How to obtain these equations?

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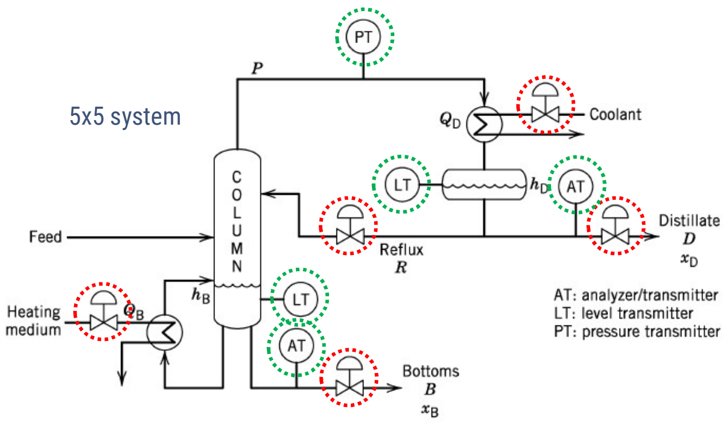
SISO and MIMO systems

- SISO system (single input, single output)
  - A single manipulated variable (input) and a single controlled variable (output) exist
- MIMO system (multiple input, multiple output)
  - Manipulated variables and controlled variables are both > 1

5x5 system



- Outputs (to be controlled)
  - $x_D; x_B$
  - P
  - $h_D; h_B$
- Inputs (to be manipulated)
  - $D; B$
  - R
  - $Q_B; Q_D$

- Decentralized control (multiloop control)
  - 5 control loops of the 1x1 type
- Centralized control (multivariable control)
  - Each MV is manipulated depending on the values of all the CVs
  - A dynamic model of the process is needed

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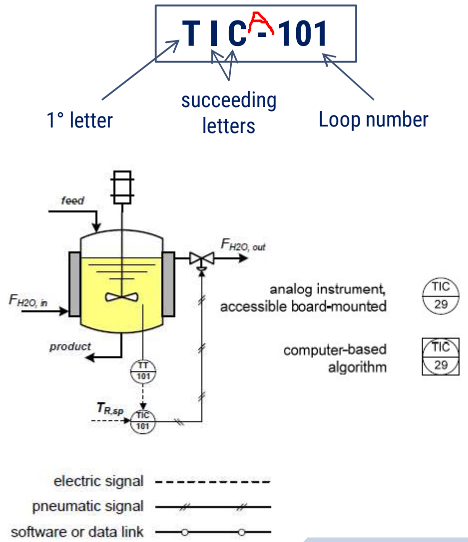
Instrumentation symbols (see SEMD Appendix D, p.487)

Letter	As the 1° letter: measured or controlled variable	As the 2° or 3° or 4° letter: function or modifier
A	Analyzer (composition)	Alarm
C	-	Controller
F	Flow rate	-
G	User's choice	-
H		High
I	Current	Indicator
L	Level	Low
P	Pressure	-
R	-	Registered
S	Speed	Switch
T	Temperature	Transmitter



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