



HAL
open science

Contrôle de paramètres dans un chémostat

Jérôme Harmand

► **To cite this version:**

Jérôme Harmand. Contrôle de paramètres dans un chémostat. Colloque National d'Assimilation de Données, Dec 2014, Toulouse, France. hal-01090655

HAL Id: hal-01090655

<https://inria.hal.science/hal-01090655>

Submitted on 2 Jun 2020

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Control of the chemostat model

*J. Harmand, SAMI research team, LBE-INRA & INRA-INRIA
MODEMIC*

Le LBE-INRA et MODEMIC



- INRA
- About 80 people



Modemic

Treating and valorize biomass within a biorefinery context

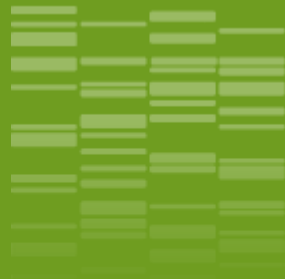


CONTEXT

- ❖ An « explosion » of –omic data : a problematic of « big data »
- ❖ High computation capacity
- ❖ A (very) important deficit in modeling education within education in biology
- ❖ How available data and modeling may help in better understanding and controlling bioprocesses?

CONTENT

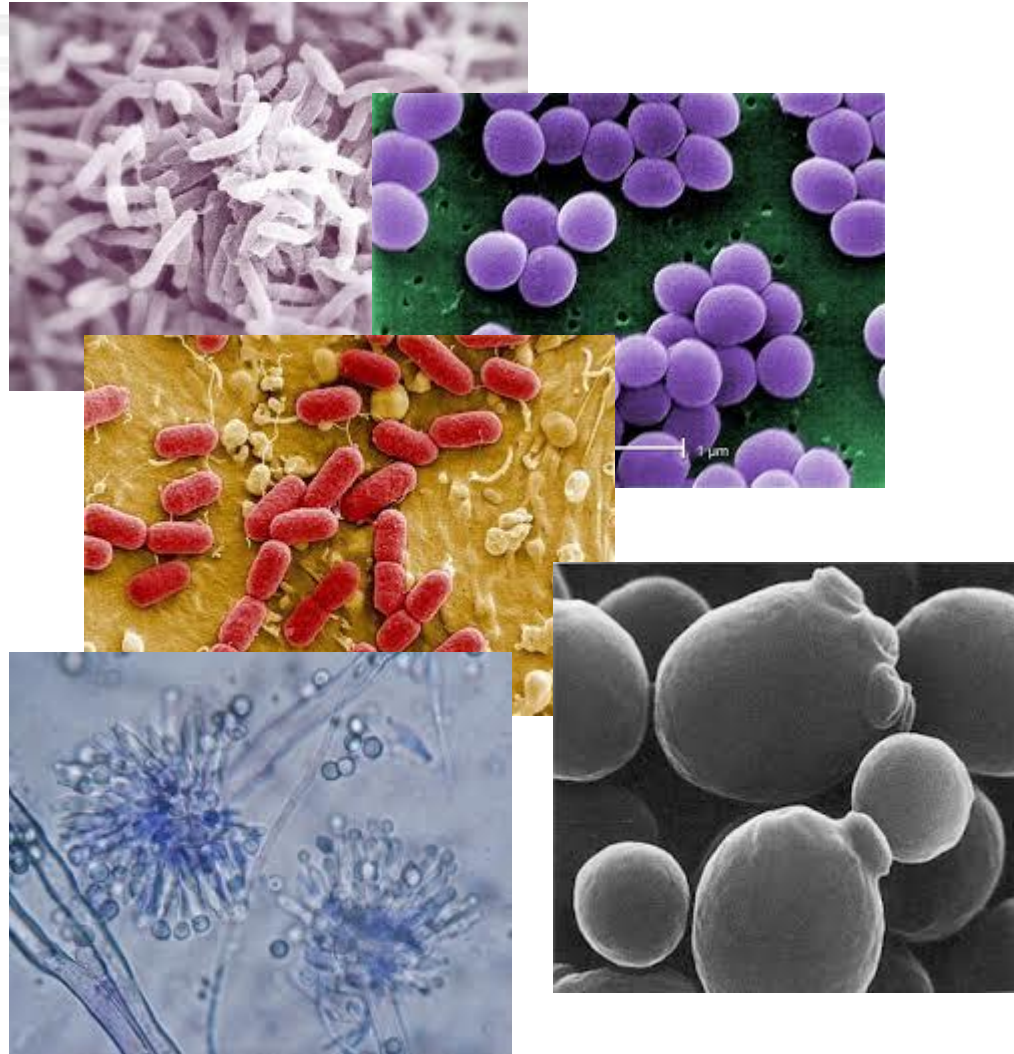
- ❖ Microbial ecosystems and the chemostat...
- ❖ Bioprocess modeling
- ❖ Observing and controlling the chemostat : a robust approach
- ❖ An example : control of the anaerobic digestion process



_01

Microbial ecosystems and the chemostat

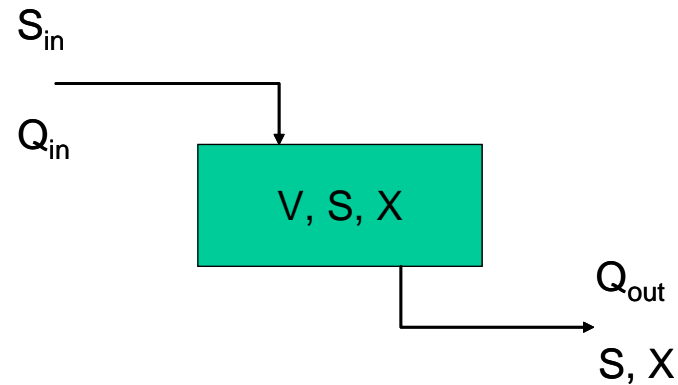
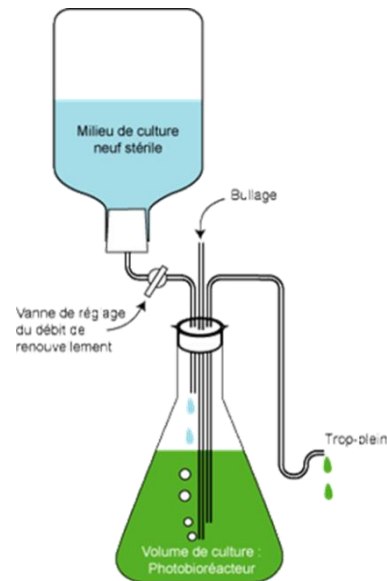
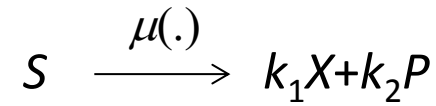
Les écosystèmes microbiens



The chemostat



« Chemostat »



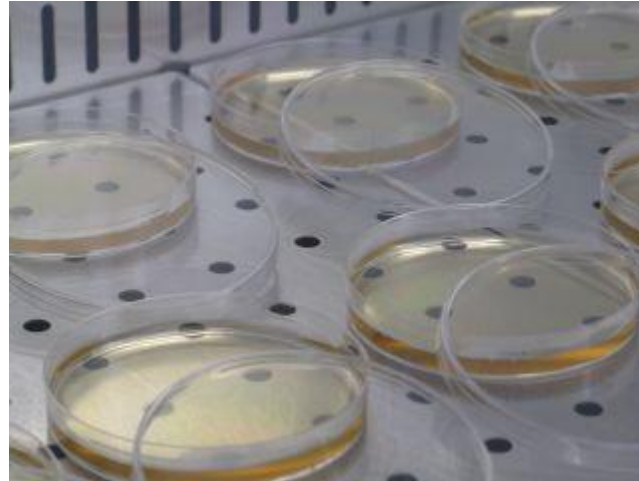
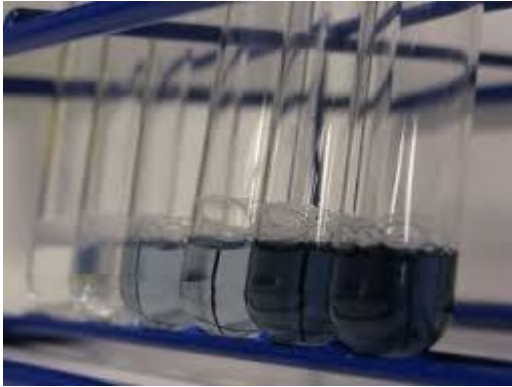
Le chemostat

The inventors of the chemostat

- Novick A. and Szilard L. (1950), *Description of the chemostat*. *Science*, 112, 715-716
- Monod, J., *La technique de culture continue theorie et applications*. *Ann. Inst. Pasteur*, 79, 390-410, 1950



High diversity of scales



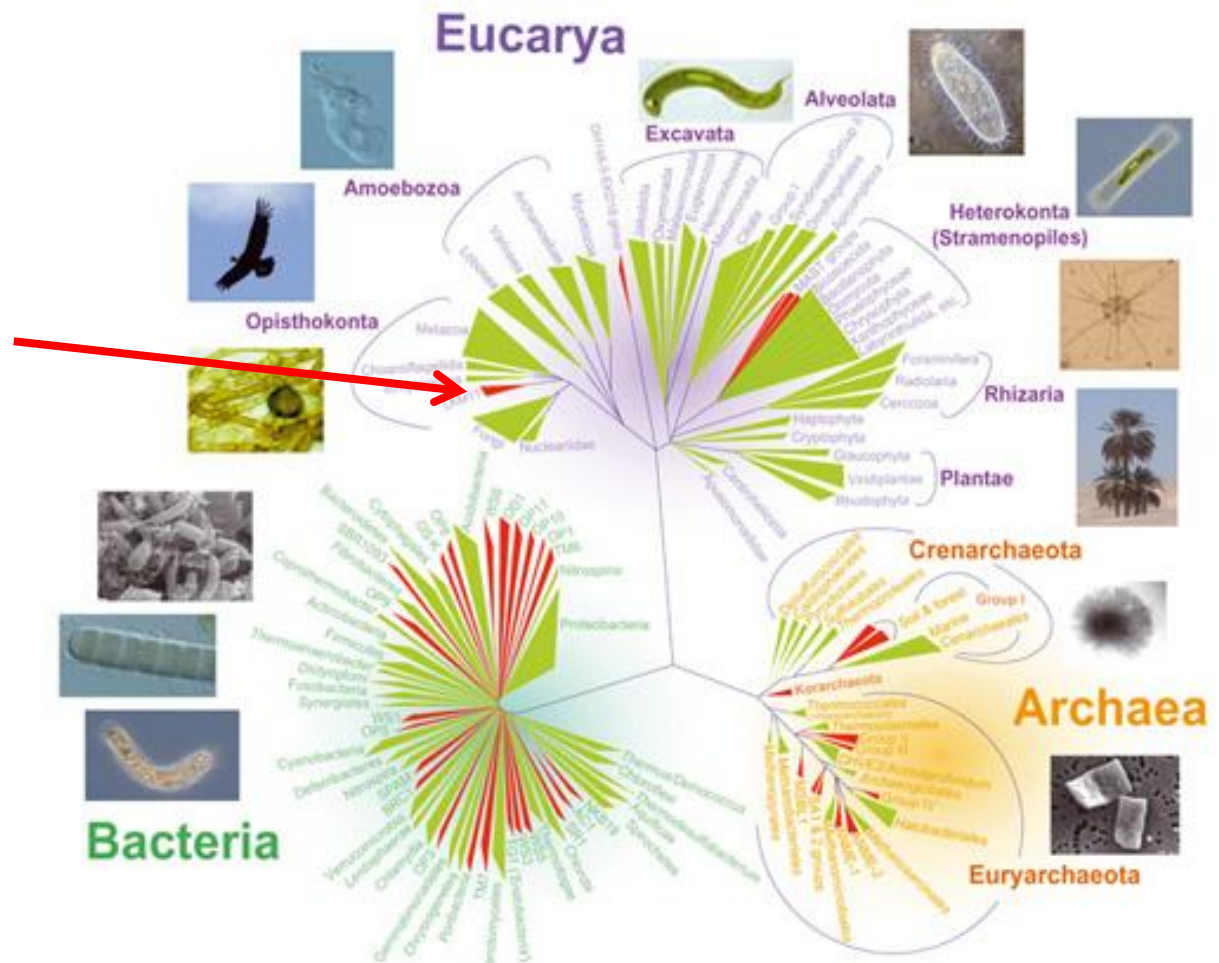
How using microbial ecosystems



Studying the functional heart of any bioprocess: a natural « complex » ecosystem

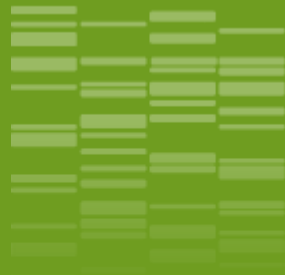
An immense world...

You, your cat and your red fish...



Conclusions

- ❑ Microbial ecosystems : complex systems;
- ❑ Used in a very high number of production/treatment fields
- ❑ The chemostat is only 60 years old;
- ❑ Important research effort...

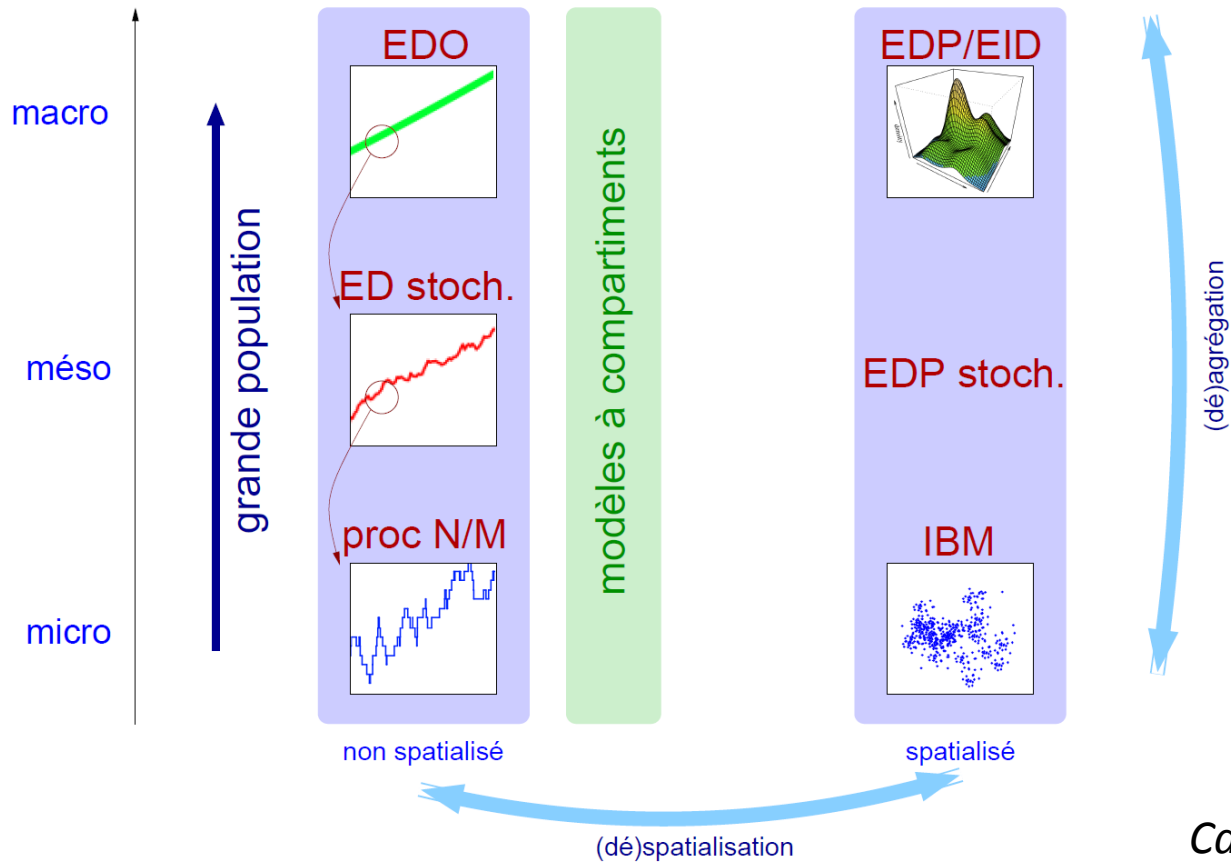


_02

Modeling

Lots of model!

Deterministic continuous dynamical models vs stochastic IBM



Campillo, 2011

Which model : the viewpoint of microbiologist...

Usually, they only know the two extreme cases : EDO-based and IBM (used for describing space)!

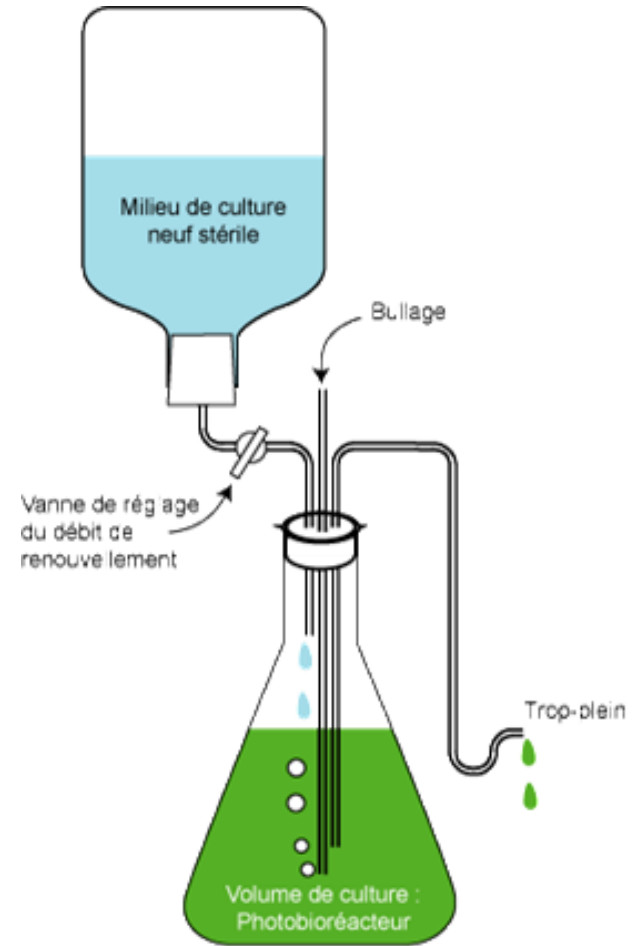
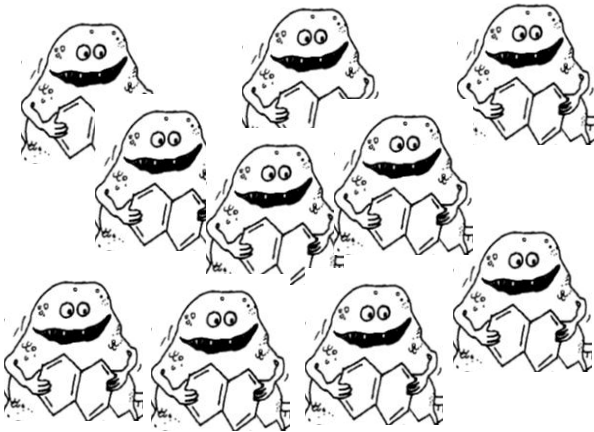
Then use of a model instead of another depends essentially of their collaboration and of their own modeling culture!

Which model : the viewpoint of modelists/mathematicians...

Such nonlinear models may be usefull for my research to be applied...

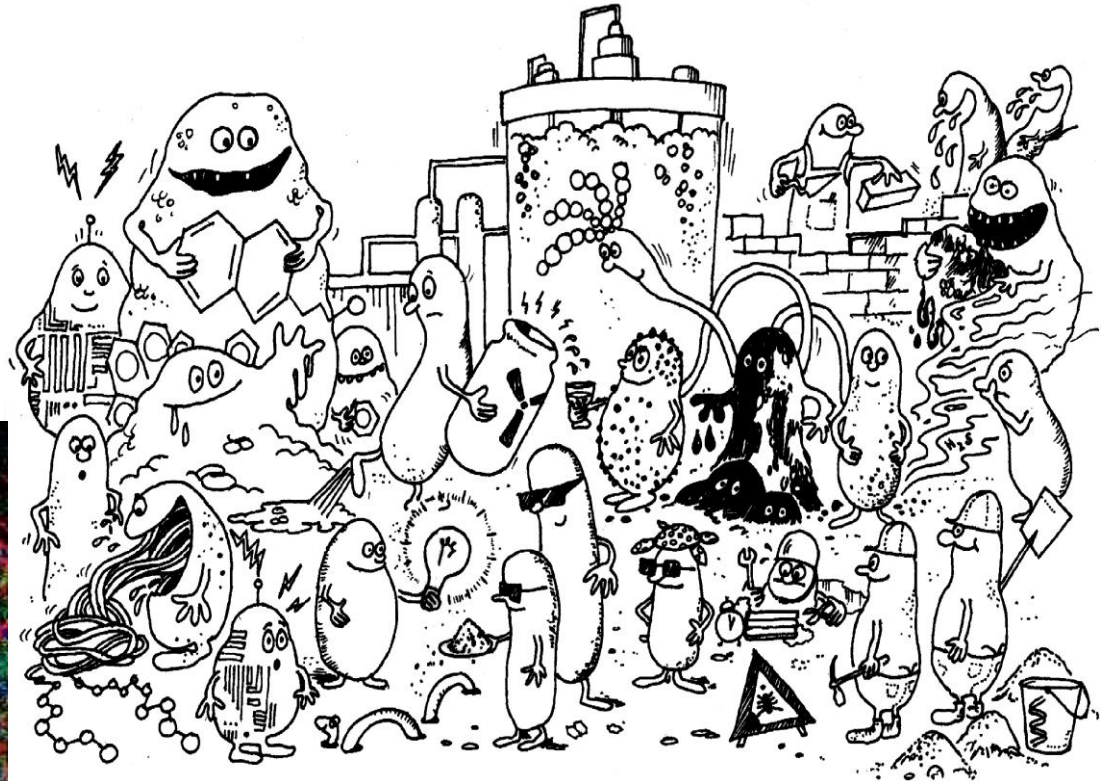
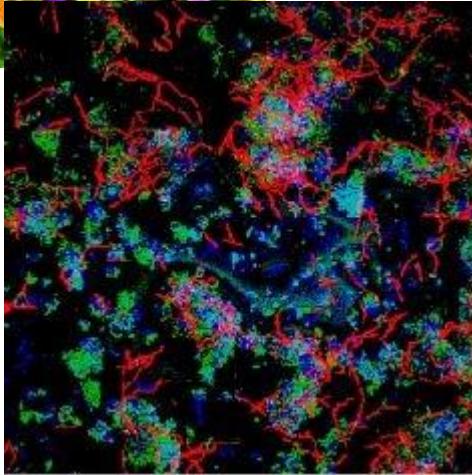
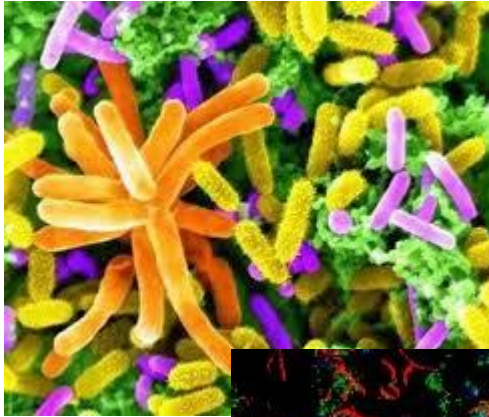
How modeling an ideal bioprocess?

□ Until recently...



How modeling an ideal bioprocess?

□ Modern biological tools reveal rather...



The chemostat model

- The associated continuous deterministic model

$$\frac{d(SV)}{dt} = \text{"Input mass of S"} - \text{"Output mass of S"} \dots$$

...+ "production" - "consumption"

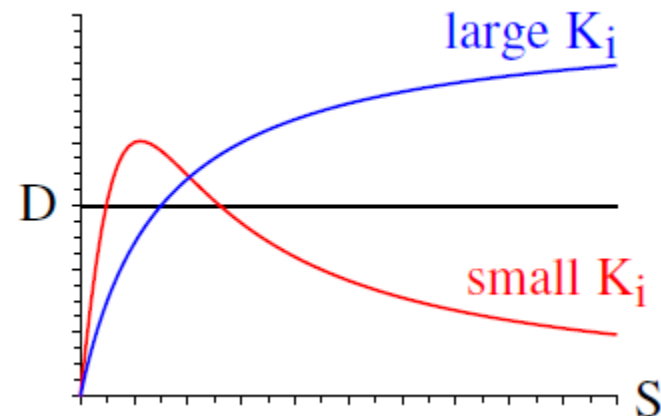
$$\begin{cases} \frac{dS}{dt} = S_{in} \frac{Q}{V} - S \frac{Q}{V} - \frac{\mu(S)}{Y} X = (S_{in} - S) D - \frac{\mu(S)}{Y} X \\ \frac{dX}{dt} = \mu(S) X - \frac{Q}{V} X = (\mu(S) - D) X \end{cases}$$

The chemostat model

□ Kinetic modeling

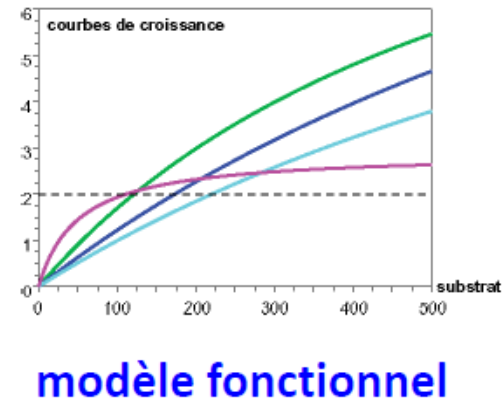
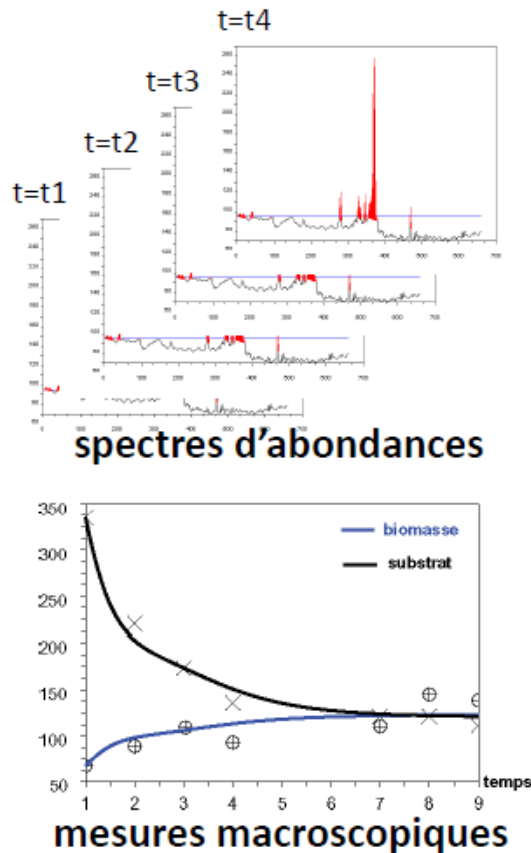
$$\begin{aligned}\dot{s} &= -\mu(s)x + D(s_{in} - s) \\ \dot{x} &= \mu(s)x - Dx\end{aligned}$$

$$\mu(s) = \frac{\bar{\mu}s}{K + s + s^2/K_i}$$



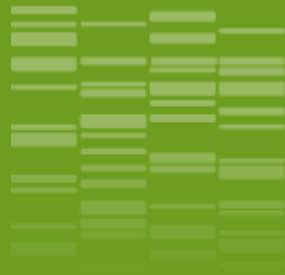
The chemostat model

□ Matching data : identifying yields and kinetics coefficients



Conclusions

- ❑ Important research on chemostat modeling;
- ❑ To study microorganism growth (ecological questions);
- ❑ To optimize its functioning...



03

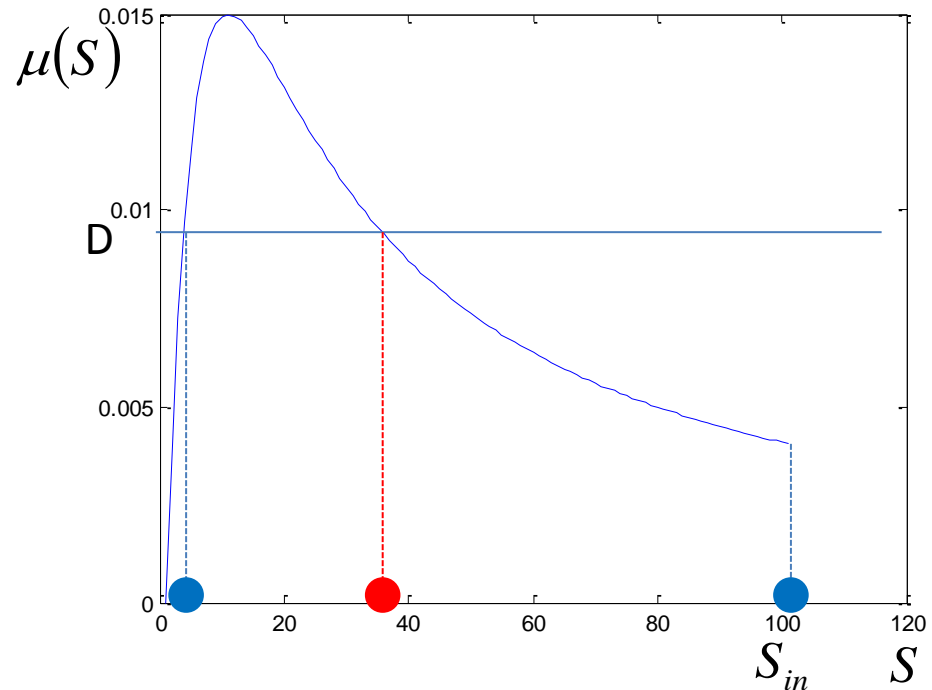
Observing and controlling the chemostat...

The chemostat model

□ Chemostat with inhibition

$$\begin{cases} \frac{dS}{dt} = (S_{in} - S)D - k\mu(S)X \\ \frac{dX}{dt} = (\mu(S) - D)X \end{cases}$$

$$\mu(S) = \frac{\bar{\mu}S}{S + K_S + \frac{S^2}{K_I}}$$



$$\bar{\mu} = 0.045, K_S = 10, K_I = 10$$

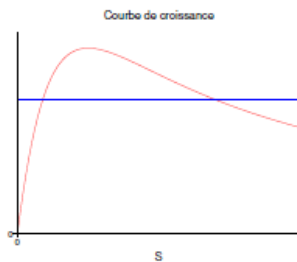
The chemostat model

□ Qualitative properties of the model



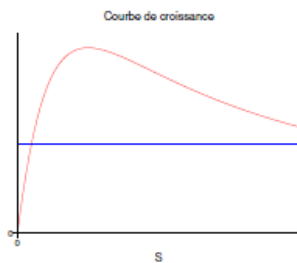
$$D > \max_{s \in [0, S_{in}]} \mu(s)$$

1 equilibrium : washout



$$\mu(s_{in}) < D < \max_{s \in [0, S_{in}]} \mu(s)$$

3 equilibria : bistability

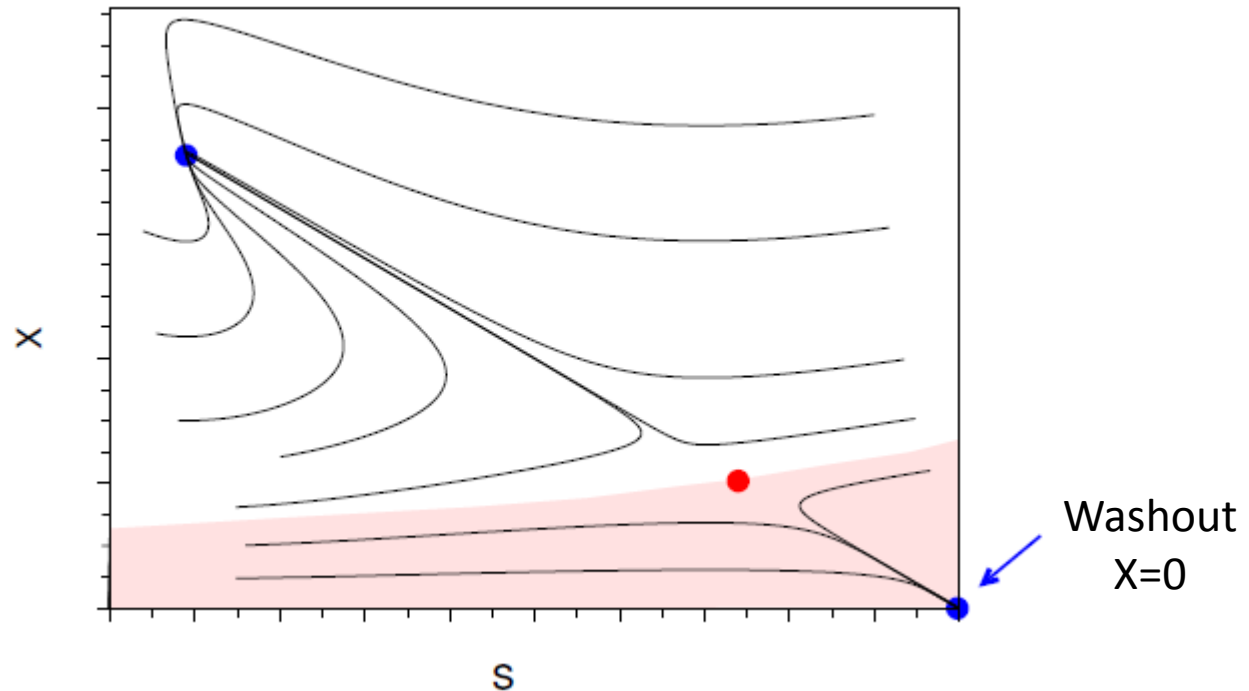


$$D < \mu(s_{in})$$

2 equilibria : 1 stable and one unstable (washout)

The chemostat model

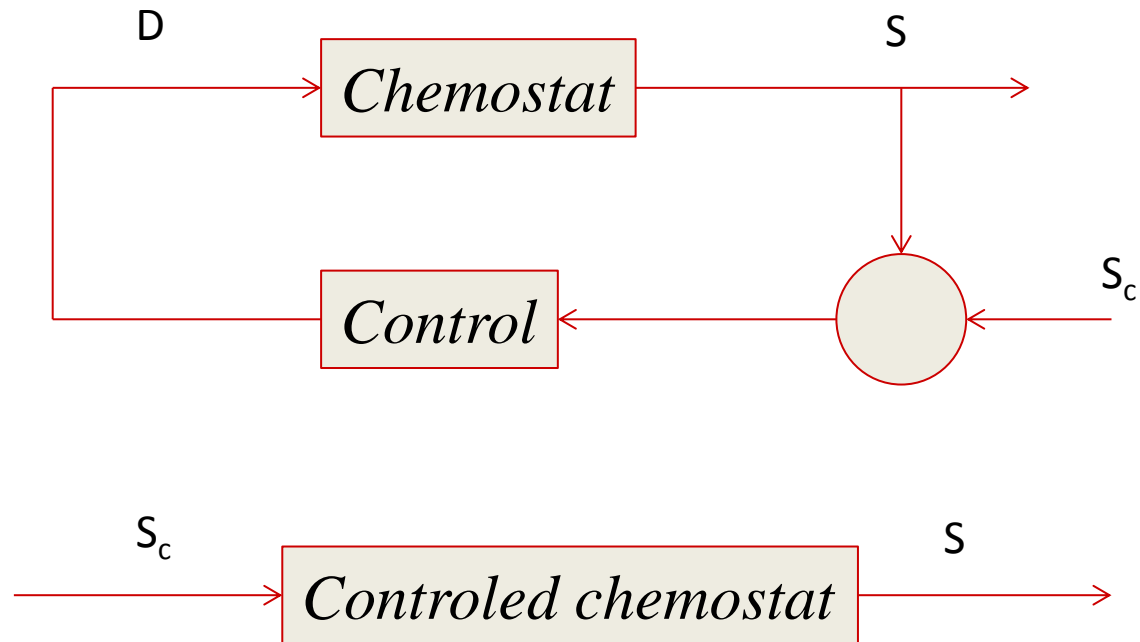
□ State space representation



Cas #2 : Under the condition $\mu(s_{in}) < D < \max_{s \in [0, S_{in}]} \mu(s)$

Controlling the chemostat

□ Closing the loop



Stabilizing the chemostat

□ Solution : Output Feedback

Example #1 : Linearizing feedback control

$$D(s, x) = \frac{\mu(s)x - \lambda(s - s^*)}{s_{in} - s}$$

Cf. Bastin et Dochain 1986

Example #2 : PI Controller

$$D(s) = G_1(s - s^*) + G_2 \int_0^t (s(\tau) - s^*) d\tau$$

Cf. Alvarez Lopez-Arenas 2012 (and many others)

Example #N : ...

Stabilizing the chemostat

□ Solution : Output Feedback

Exemple #1 : Linearizing feedback control

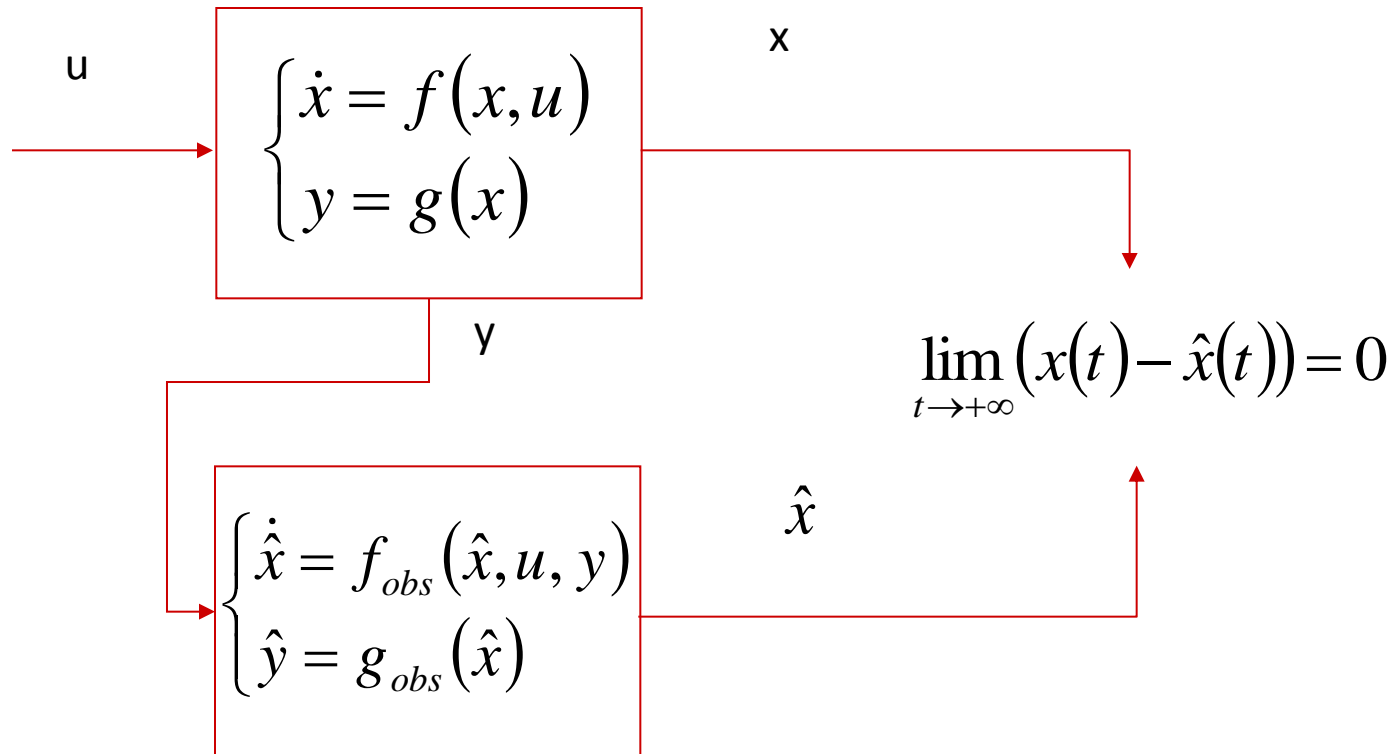
$$D(s, x) = \frac{\mu(s)x - \lambda(s - s^*)}{s_{in} - s}$$

Drawback : We must know everything! (mu + sin, s and x...)

Assuming we only know s and we have uncertainty on others input and parameters, how stabilizing the system with guaranteed performances?

Stabilizing the chemostat

- Solution : A robust observer scheme



Stabilizing the chemostat

- Solution : An interesting change of variables

$$\left\{ \begin{array}{l} \frac{d\hat{Z}(t)}{dt} = (S_{in} - \hat{Z}(t))D(t) \\ \hat{Z}(0) = \hat{Z}_0 \\ \hat{X}(t) = Y(\hat{Z}(t) - S(t)) \end{array} \right.$$

$$\lim_{t \rightarrow +\infty} Z(t) = S_{in}$$

Stabilizing the chemostat

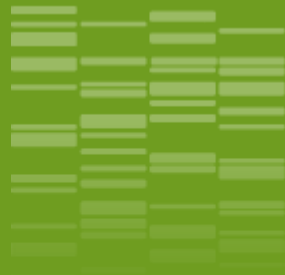
- Robustifying the asymptotic observer with respect to uncertainty (inputs + measurements + parameters)

$$\left\{ \begin{array}{l} \frac{d\hat{Z}^-(t)}{dt} = (S_{in}^- - \hat{Z}^-(t))D(t) \\ \hat{Z}^-(0) = \hat{Z}_0^- \\ \hat{X}^-(t) = Y(\hat{Z}^-(t) - S(t)) \end{array} \right.$$

$$\left\{ \begin{array}{l} \frac{d\hat{Z}^+(t)}{dt} = (S_{in}^+ - \hat{Z}^+(t))D(t) \\ \hat{Z}^+(0) = \hat{Z}_0^+ \\ \hat{X}^+(t) = Y(\hat{Z}^+(t) - S(t)) \end{array} \right.$$

$$\lim_{t \rightarrow +\infty} Z^-(t) = S_{in}^-$$

$$\lim_{t \rightarrow +\infty} Z^+(t) = S_{in}^+$$

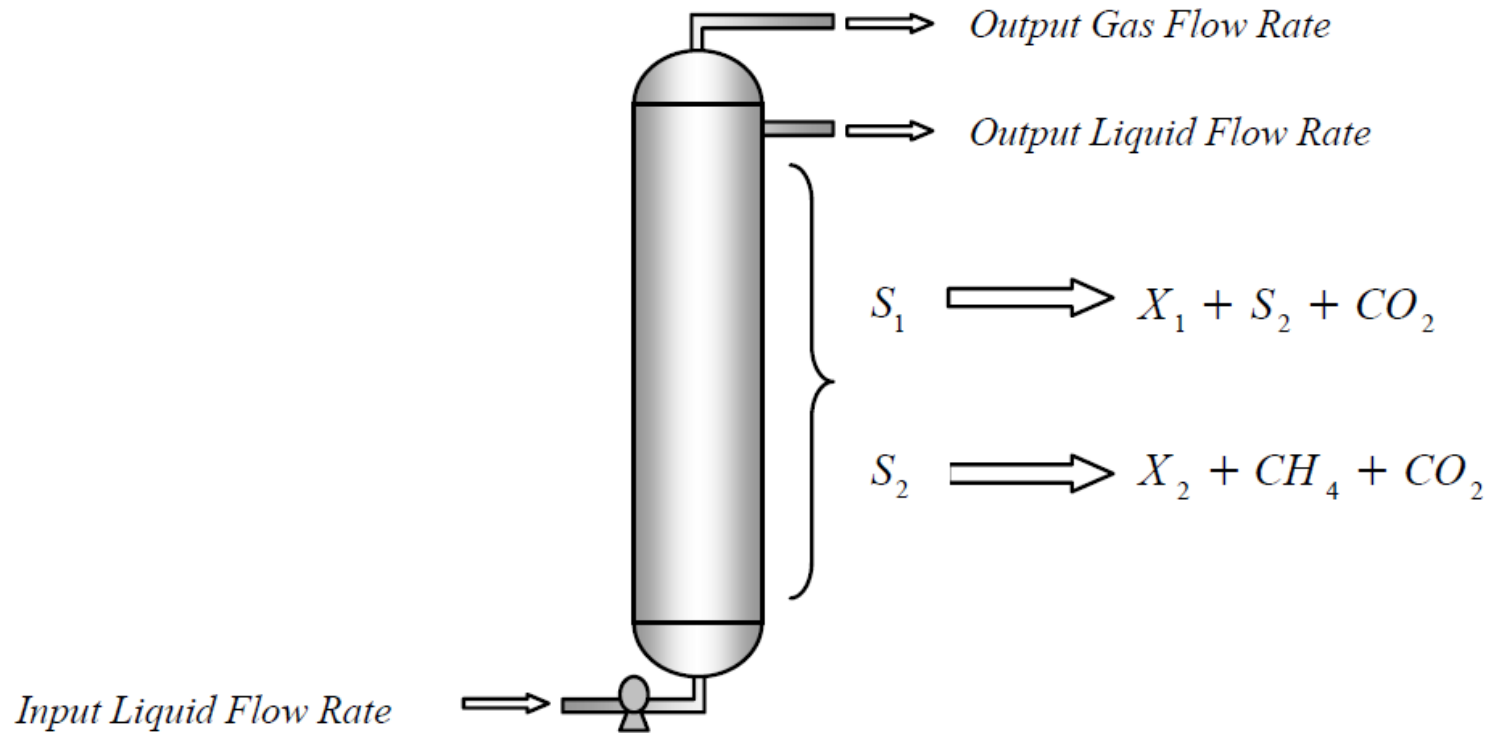


_04

**An exemple : controlling the
anaerobic digestion process**

Stabilizing the chemostat

□ Application



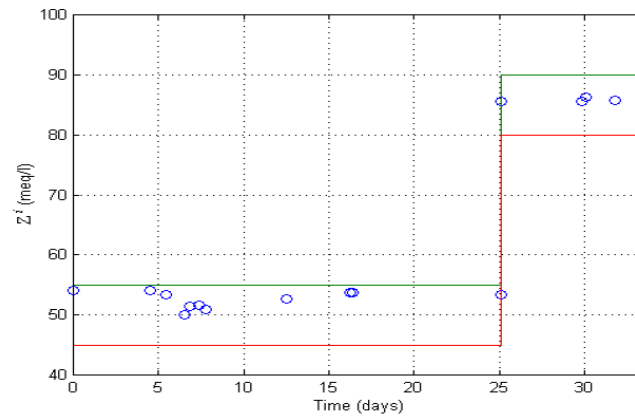
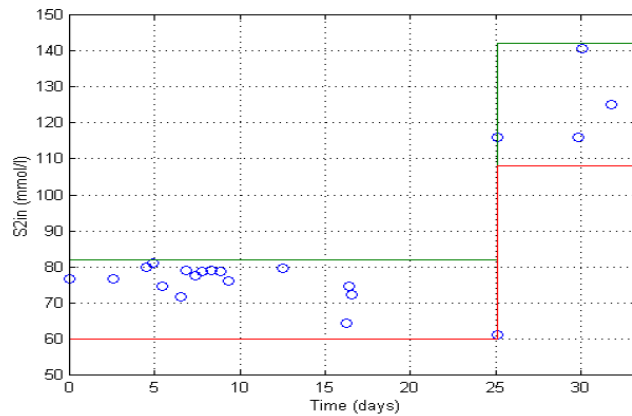
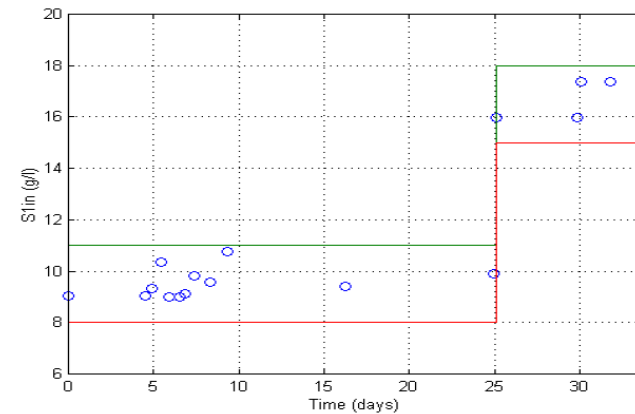
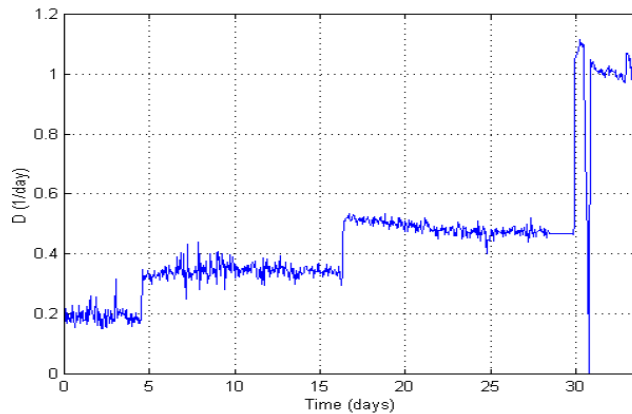
Stabilizing the chemostat

□ The model

$$\left\{ \begin{array}{l} \dot{X}_1 = (\mu_1 - \alpha D)X_1 \\ \dot{X}_2 = (\mu_2 - \alpha D)X_2 \\ \dot{Z} = D(Z^i - Z) \\ \dot{S}_1 = D(S_1^i - S_1) - k_1\mu_1 X_1 \\ \dot{S}_2 = D(S_2^i - S_2) + k_2\mu_1 X_1 - k_3\mu_2 X_2 \\ \dot{C}_{\text{TI}} = D(C_{\text{TI}}^i - C_{\text{TI}}) + k_4\mu_1 X_1 + k_5\mu_2 X_2 - Q_{\text{CO}_2} \end{array} \right.$$

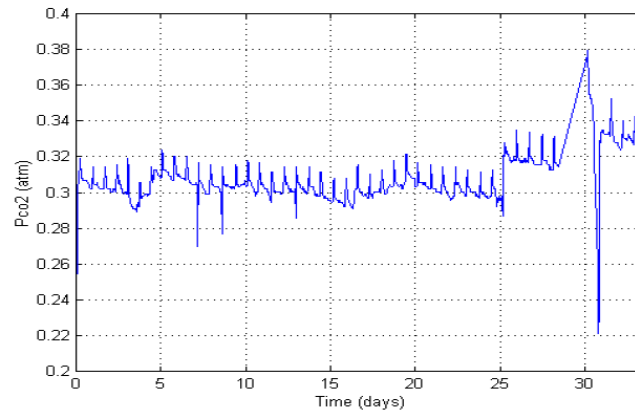
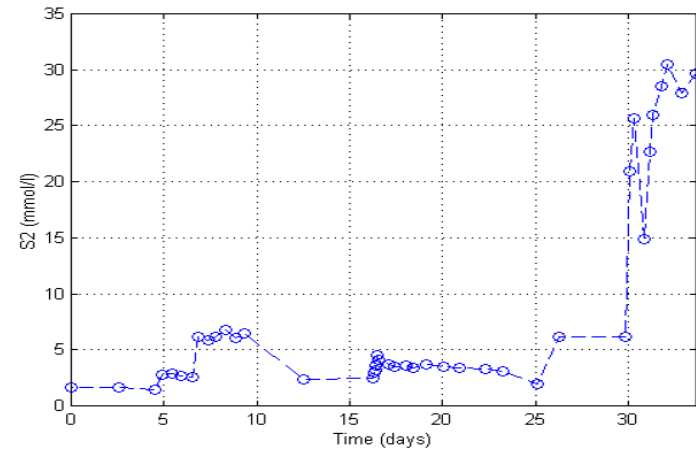
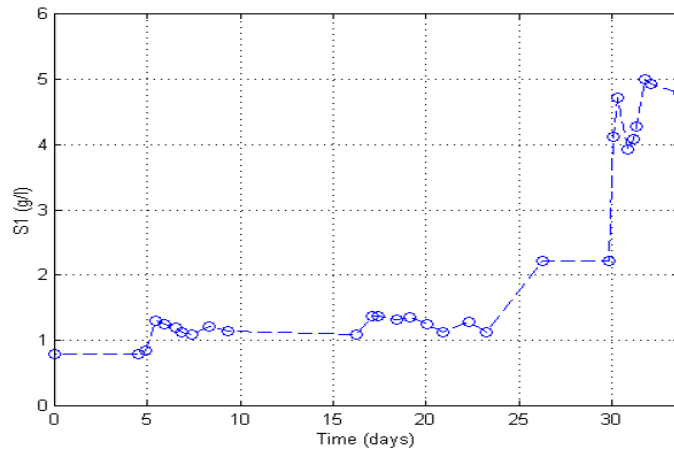
Stabilizing the chemostat

□ The robust observer : the inputs



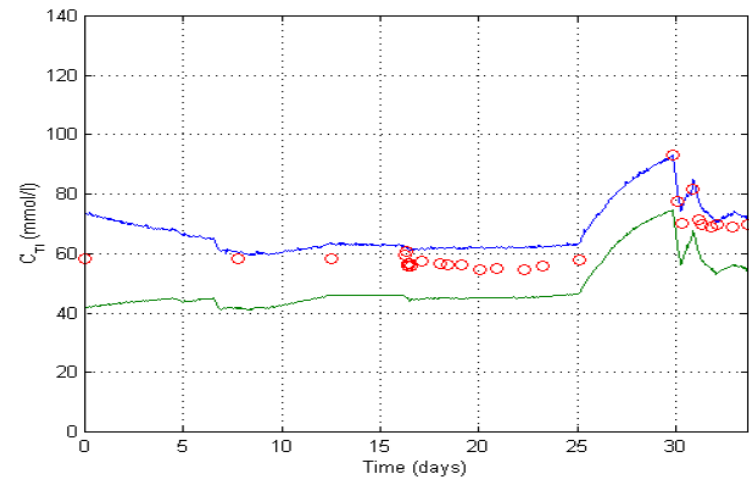
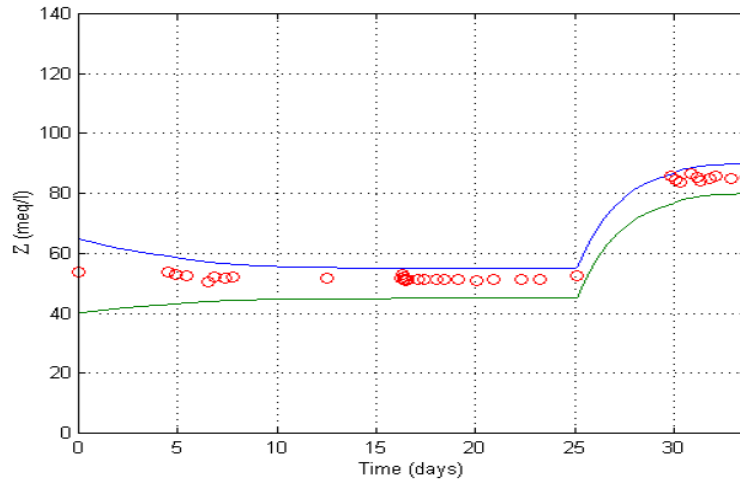
Stabilizing the chemostat

□ The robust observer : the measurements



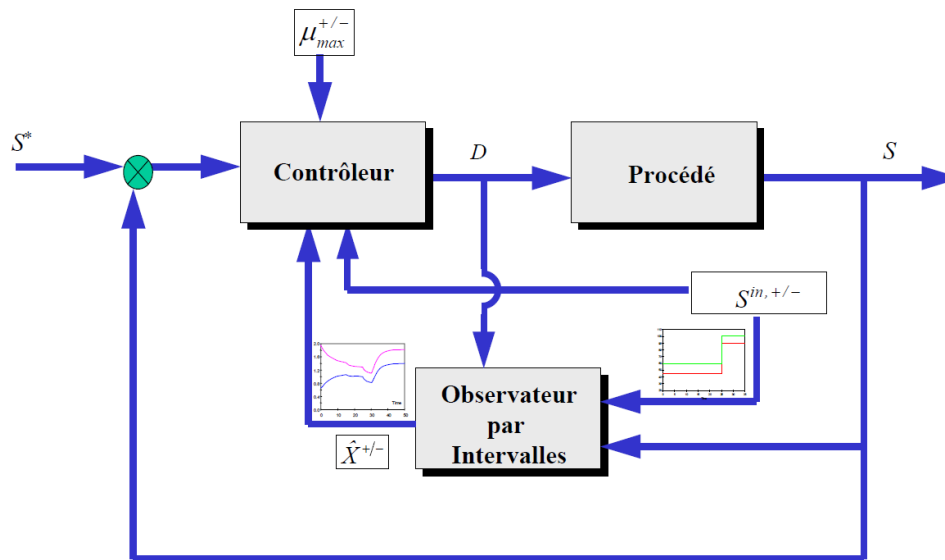
Stabilizing the chemostat

□ The robust estimations



Stabilizing the chemostat

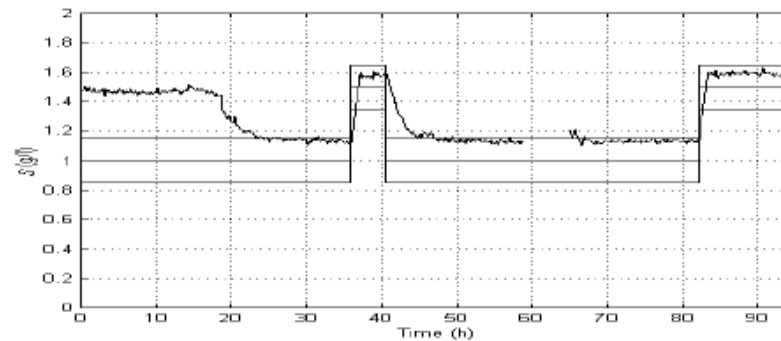
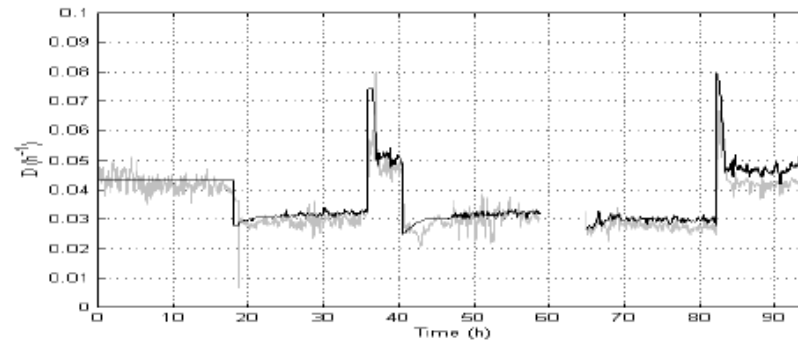
- Coupling the robust observer with the robust control design : application to the anaerobic digestion

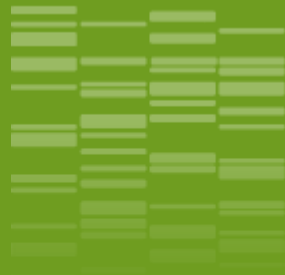


$$D(t) = \text{sat}_{[0, \bar{D}]} \left(\frac{k\mu^{+/-}(t)\hat{X}^{+/-}(t) - \lambda(S(t) - S^*)}{S_{in}^{+/-}(t) - S(t)} \right)$$

Stabilizing the chemostat

□ Results : control and controlled variable





_04

Conclusions and perspectives

Conclusions and perspectives

- Model of the chemostat
- Stabilizing robustly the chemostat
- Towards biocontrol approaches...



Thank you for your attention!