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Department of Applied Mathematics, Biometrics and Process Control

On the limitations of short term experiments for the calibration of dynamic models of activated sludge wastewater treatment

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The Millenium for Microbiology

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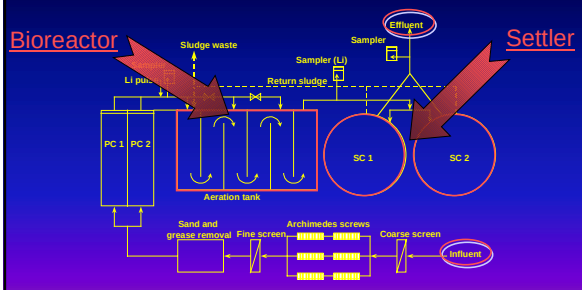
Problem Statement

Biological Wastewater Treatment by Activated Sludge



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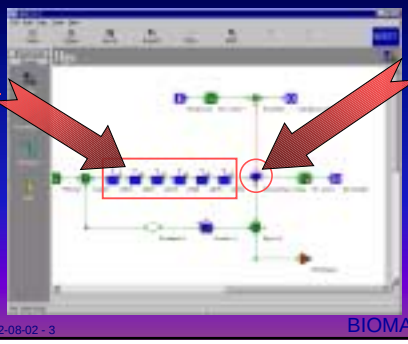
Problem Statement (cont'd)

Process optimisation via model simulation

Bioreactor

Settler



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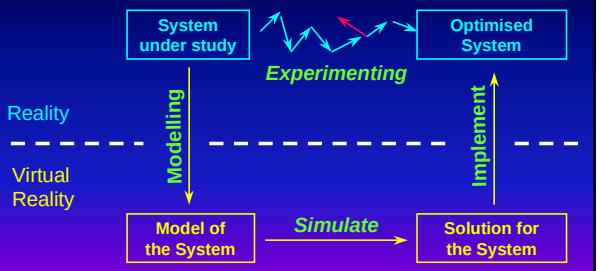
Why Modelling & Simulation ?

Solving Problems for complex systems



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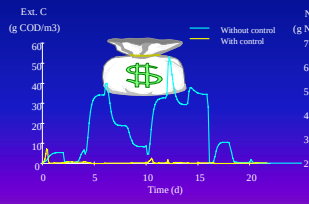
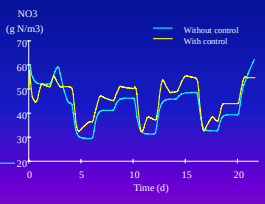
Example of model-based optimisation

- Industrial plant with nitrogen problem:
  Question: Include automatic control or not ?

External Carbon for Denitrif.



Effluent nitrate conc.



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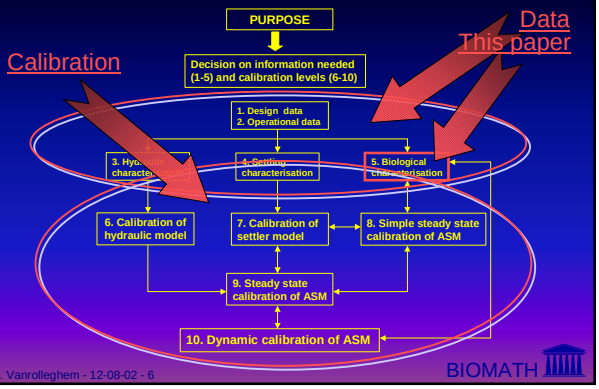
How to get a good model ?



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Good quality experimental data for biological characterisation

- Process related information
  - nitrification (NH_4 --> NO_3)
  - oxidation of organic pollutants
- Fast: experiments cannot take too much time
- Cost-effective
  - simple experimental set-ups & little labour involved
- Accurate: little error in raw data
- Sensitive: data quickly reflect change in characteristics
- Relevant
  - organisms behave similarly in experiment as in full-scale

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Respirometry as preferred method

- Process related information
  - respirometry = measurement of biological oxygen uptake
  - oxygen consumption for nitrification & organics oxidation
- Fast: experiments take approx. 1-2 hr
- Cost-effective
  - aerated vessel + dissolved oxygen probe
  - no lab analysis; automatic data collection on PC
- Accuracy: < 1% error on respiration rates
- Sensitivity: 0.01 mg O_2/l = 10 ppb !
- ***Relevant data ???***

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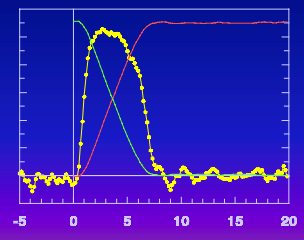
Batch respirometry: a typical data set

- Inject a given amount of substrate to endogenous sludge
- Substrate concentration decreases as it is degraded
- Oxygen consumed ≈ substrate degraded
- Oxygen uptake rate (OUR) ≈ slope of degradation



OUR measurements tell us something about degradation characteristics of sludge !

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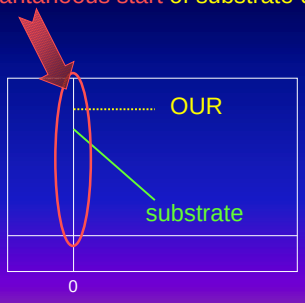
Problem 1 with the data set

- Classic (Monod) biodegradation models predict instantaneous start of substrate degradation



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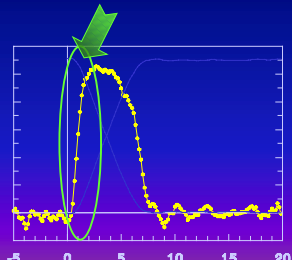
Problem 1 with the data set

- Classic (Monod) models predict instantaneous start of substrate degradation
- Observations show a start-up phenomenon



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Understanding of Problem 1

Three hypotheses:

- Dissolved oxygen electrode ?
- Mixing of the substrate in the reactor ?
- Diffusion of the substrate in the sludge floc ?

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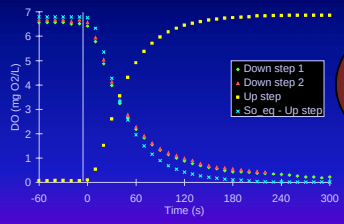
Hypothesis 1

OUR is calculated from raw dissolved oxygen data

Thus: DO probe dynamics will influence resulting OUR data



Experiment: Step response to characterise DO probes

Effect of slow DO probe dynamics cannot be neglected but is insufficient to explain findings !

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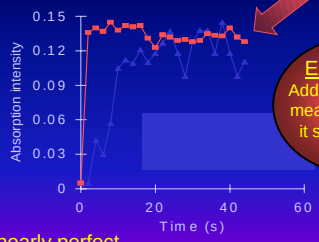
Hypothesis 2

Is mixing of the injected substrate sufficiently fast ?

=> Mixing characterisation with fluorescent tracer test



Experiment: Add fluorophore & measure how fast it spreads in the reactor

Mixing is nearly perfect and, thus, cannot be the cause of start-up phenomenon

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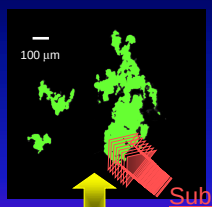
Hypothesis 3

Is the substrate diffusion rate into the floc limiting ?



Substrate

How to test this ? Via single cell culture !

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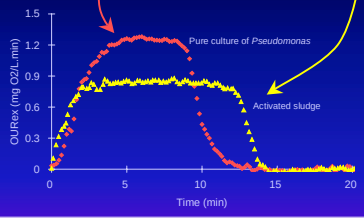
Hypothesis 3 testing

Pure culture of *Pseudomonas* vs. Activated sludge



The same behaviour was observed
Thus, no diffusion limitation occurs in sludge !

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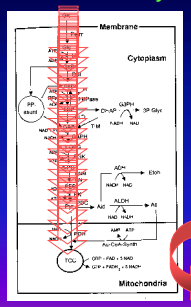
Last hypothesis !

Metabolism of substrates induces delay ?

Inspired by work in group of M. Reuss:

"In vivo analysis of metabolic dynamics of *S. cerevisiae*"



O_2

H_2O

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Last hypothesis: Experimental Evidence

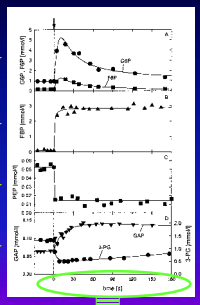
Dynamic evolution of intermediates inside yeast cell after addition of a pulse of glucose

G6P, F6P

Fruc-1,6-bis-P

PEP

GAP, 3-PG



Timing (2') looks appropriate !

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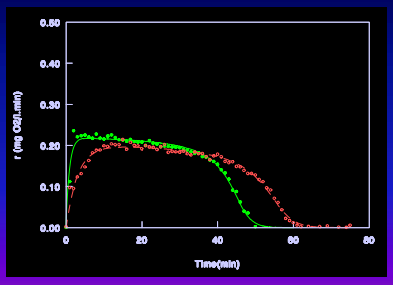
Nitrifiers start-up depends on history

Immediate NH_4 addition vs. addition after 1 famine day



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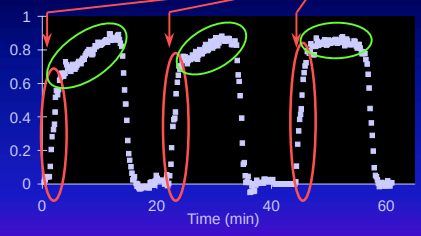
Problem 2: Another phenomenon...

Respirometric response after consecutive acetate additions:



Response is not reproducible !!

Approx. 1 hr needed to stabilise, but returns after 1 famine day

Enzyme activation ?

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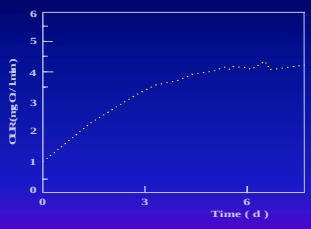
And yet another one ...

Long term evolution of maximum OUR of a sludge
(≈ max. substrate degradation rate) :



Evolution over days ==> change in microbial population

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Take home

- Why do we model ? ==> complex system optimisation
- Biological characterisation of activated sludge (1/10)
  - respirometry as preferred method
  - fast, cheap, cost-effective, accurate, sensitive
  - process related information, but is it relevant information ?
- Start-up phenomena triggered our attention (2 min)
  - 3 physical hypotheses turned out not to be valid
  - metabolic phenomena seem to be a good hypothesis
- Further, slower, start-up phenomena were observed
  - enzyme activation (1 hr)
  - microbial population dynamics (5 d)

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Take home

Consider both physical and microbial properties when designing experiments to characterise the biological processes occurring in activated sludge

Serious limitations have (still) to be overcome when performing lab scale experiments to obtain relevant information on full-scale behaviour

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