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On-line instrumentation in wastewater treatment processes: How to get the right information at the right moment and efforts to spend concerning the maintenance

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These are preliminary lecture notes, intended only for distribution to participants

On-Line Instrumentation in Wastewater Treatment Processes : How to Get the Right Information at the Right Moment and Efforts to Spend Concerning the Maintenance

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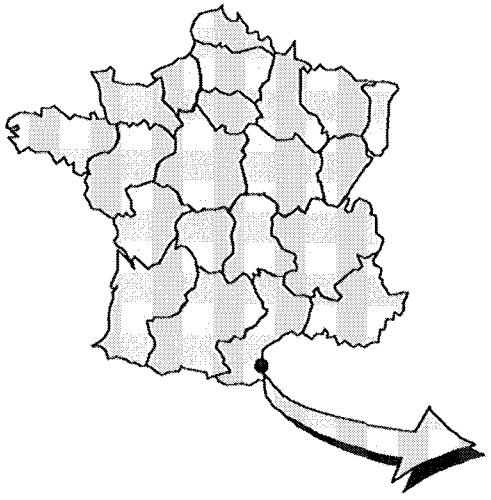
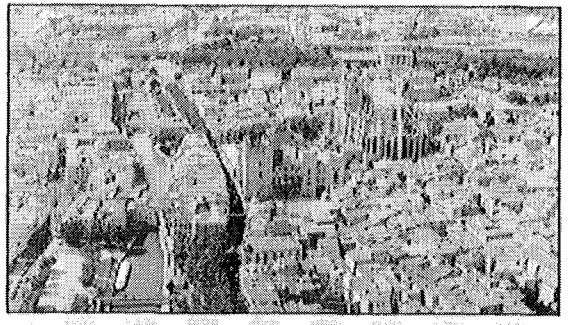
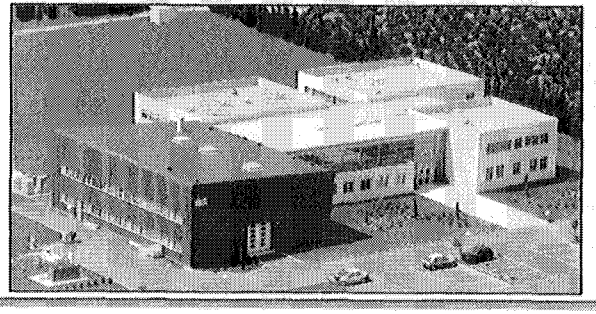
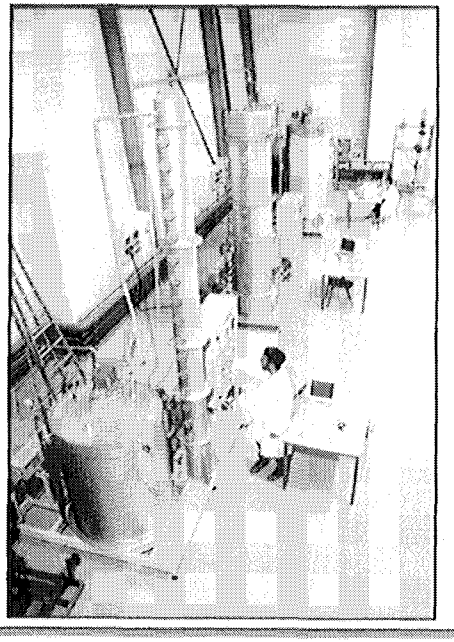








INRA

Contents of the Presentation

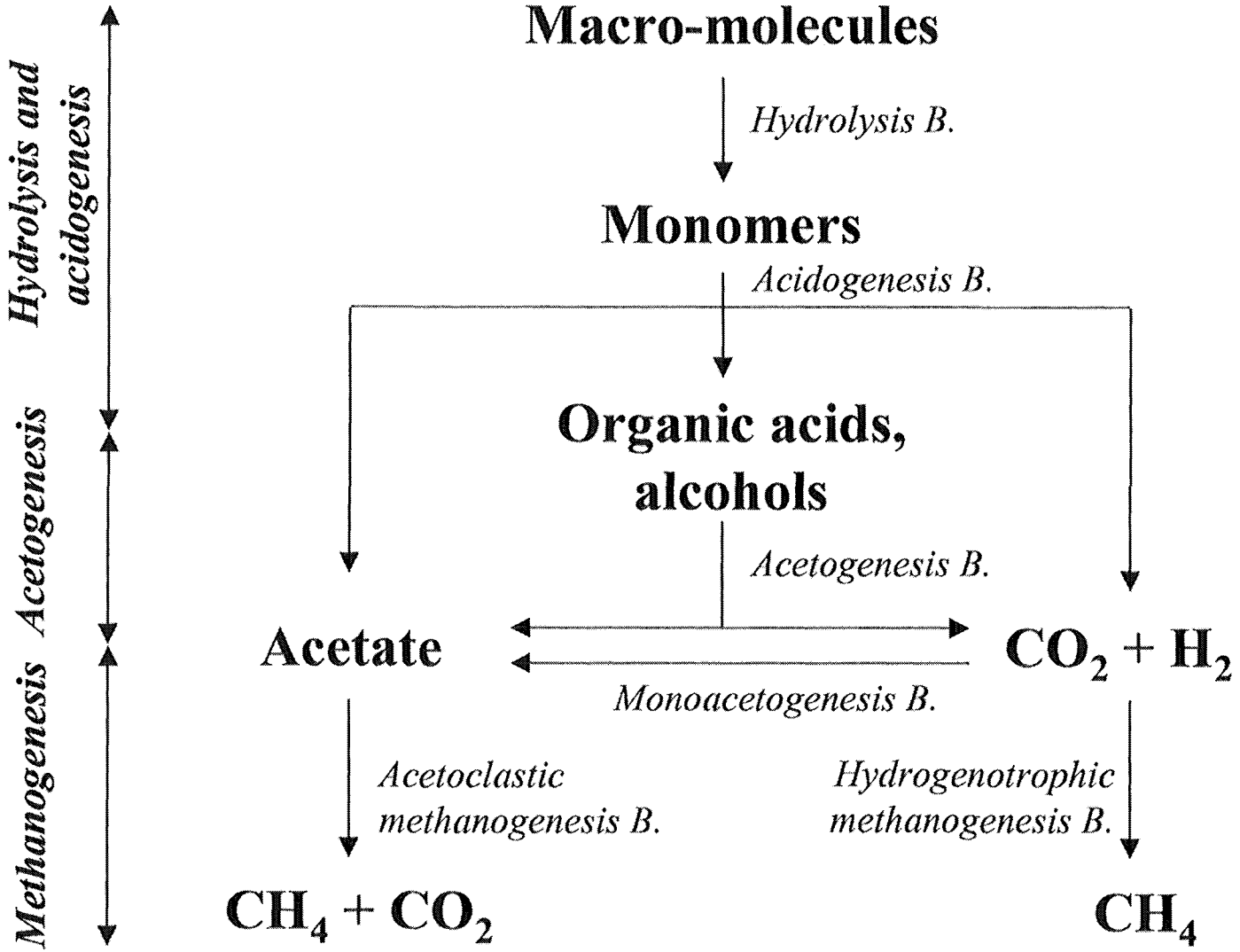
1) The anaerobic digestion process

2) Some examples of (off-line) sensors

3) Practical illustration of on-line sensors

4) Benefits from on-line instrumentation

The Anaerobic Digestion Reaction Scheme



Applications of Anaerobic Digestion

- ✓ Carbon removal of wastewater
- ✓ Production of energy (biogas)
- ✓ Reduction of sludge production
- ✓ Treatment of solid wastes (agricultural, industrial, urban)
- ✓ Decontamination of soils (organochlorine)
- ✓ Discolouration of effluents

Anaerobic Digestion as a WWTP

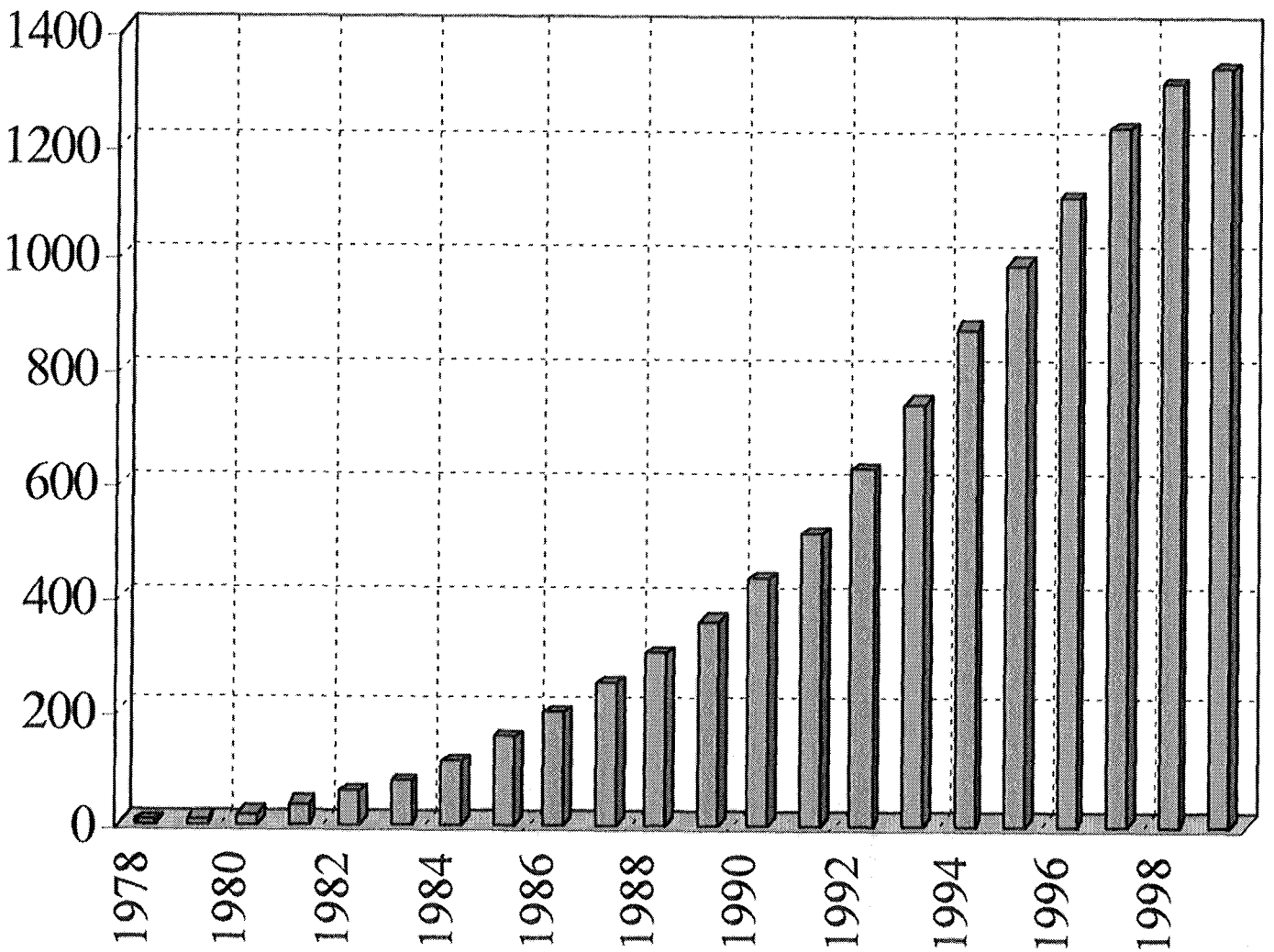
Advantages

- ✓ Naturally present in the environement
- ✓ No need of energy
- ✓ Production of valorizable biogas
- ✓ High loading rate achievable (up to 100 kg of COD/m^3/d)
- ✓ Low sludge production
- ✓ Works with effluents whith low N/COD and P/COD ratio
- ✓ High efficiency (80 to 98 % removal of COD)

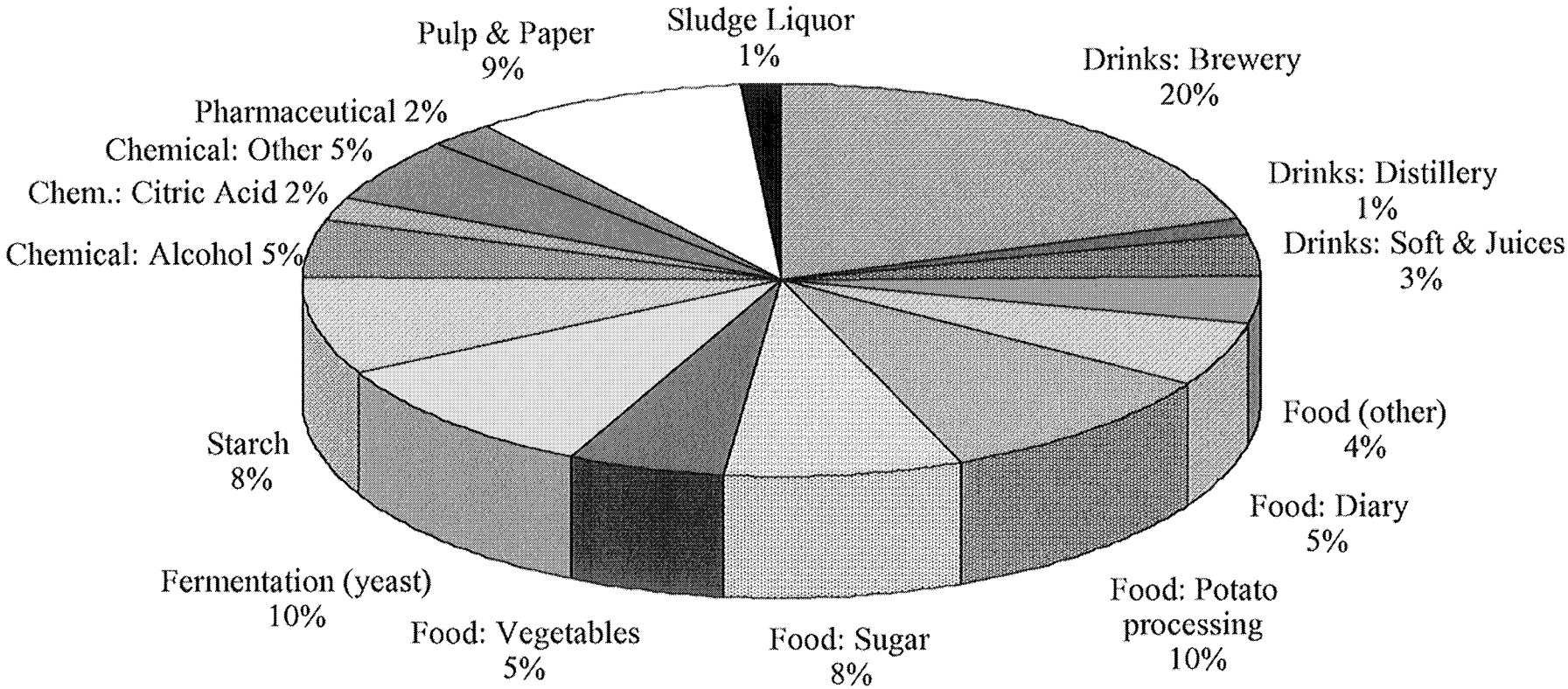
Drawbacks

- ✓ Considered as a pretreatment
- ✓ Not really suitable for diluted effluent
- ✓ Slow growth of microorganism
- ✓ Sensitivity to organic overloads (biological system / size)

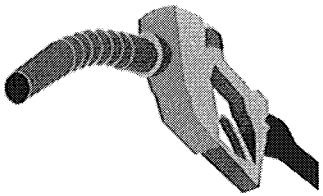
Number of Industrial Applications worldwide



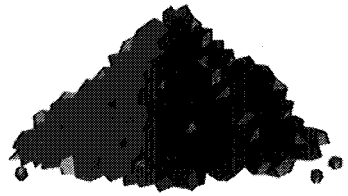
Types of Industries using AD Processes



Biogas is valorizable

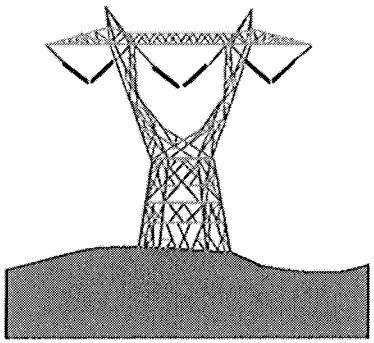


1.15 litre
of gasoline



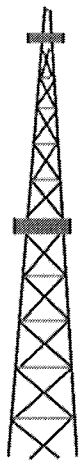
1.3 kg
of charcoal

1 m³ of methane = 8570 kcal



9.7 kW/h
of electricity

0.94 m³
of natural gas



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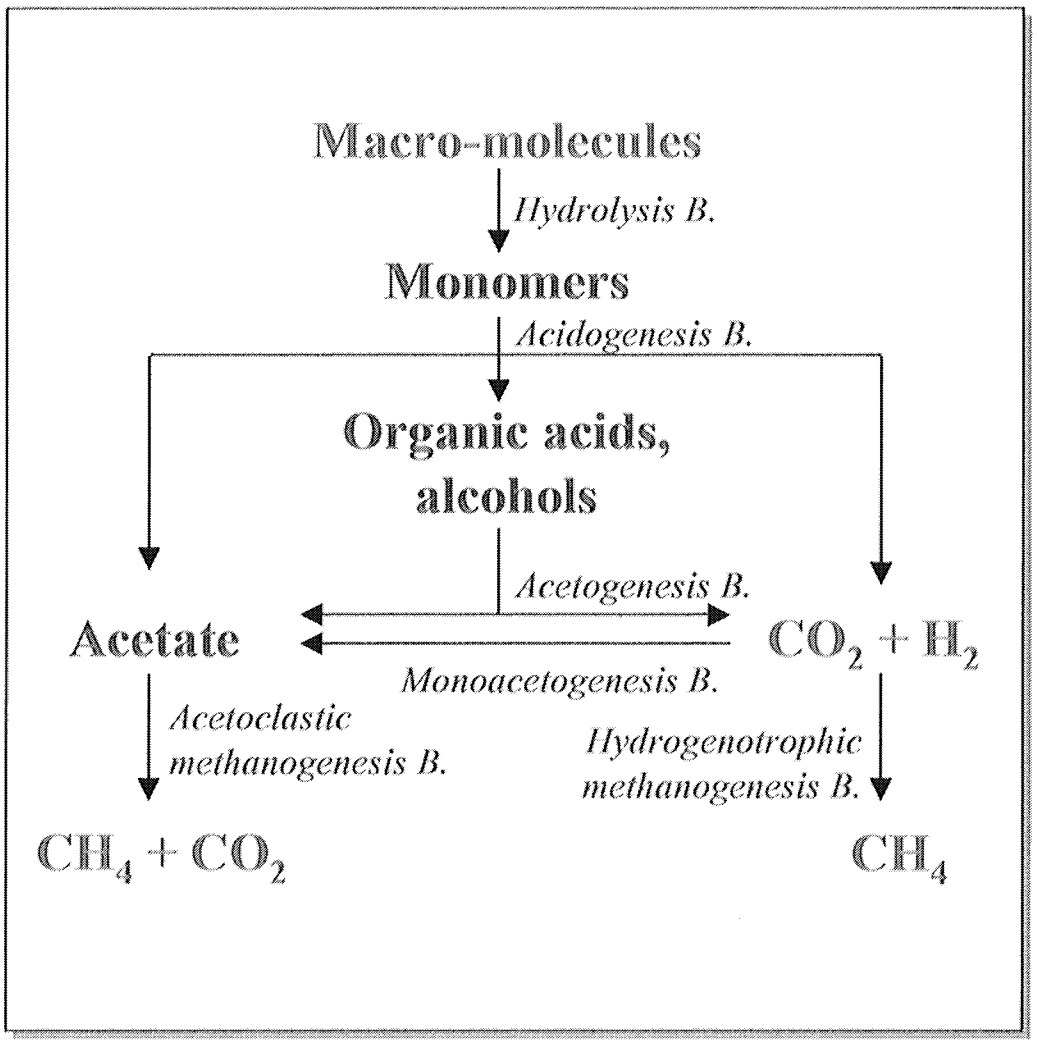
The Anaerobic Digestion Reaction Scheme

***Objective* : Get closer to the microorganisms**

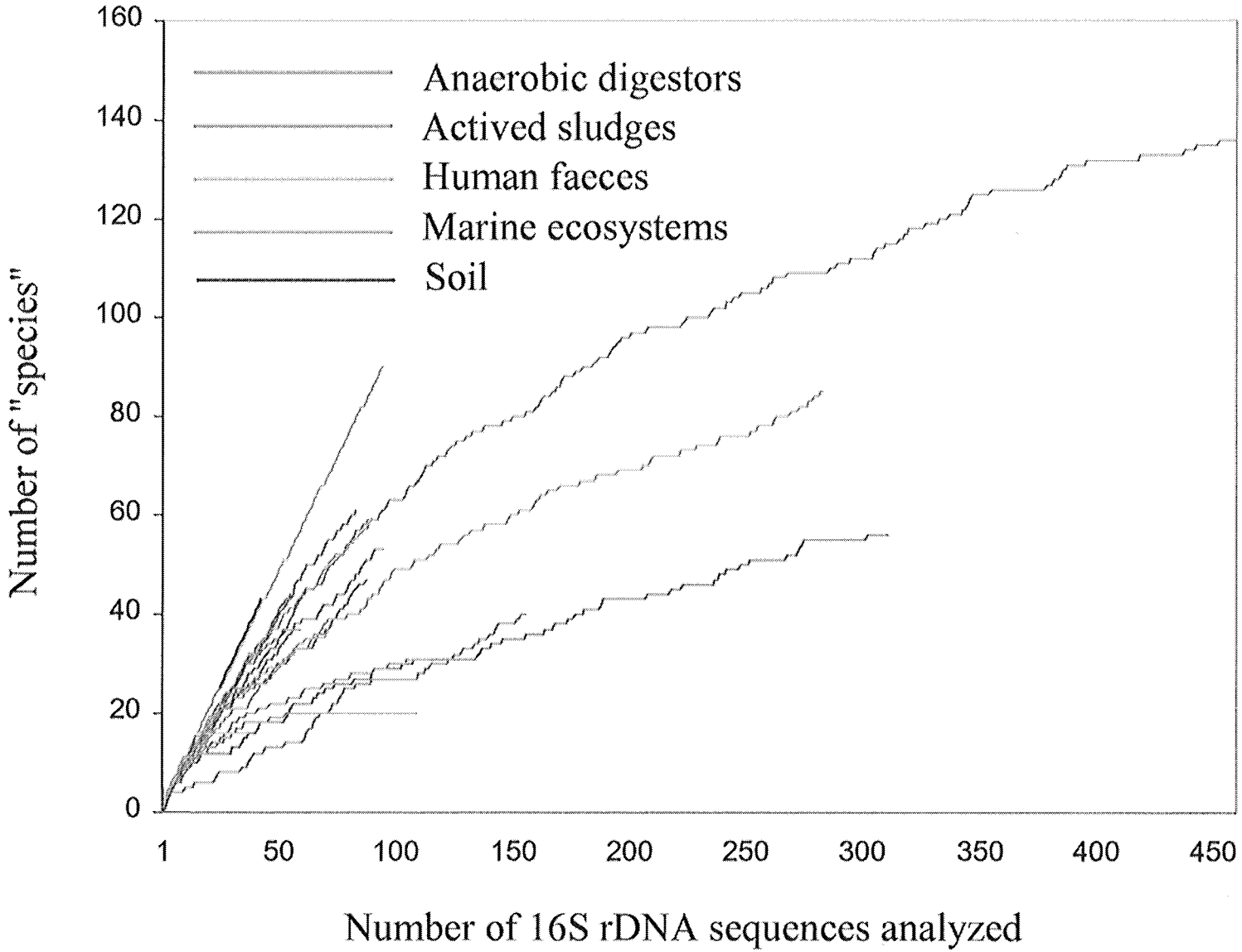


In the solid phase :
Difficult
(samples taking)

In the **liquid phase** :
Difficult
(suspended solids and global measurement of biomass)

In the gas phase :
Easy but end products
(aggregated measurements and delay)

Anaerobic Digestion is a Complex Ecosystem

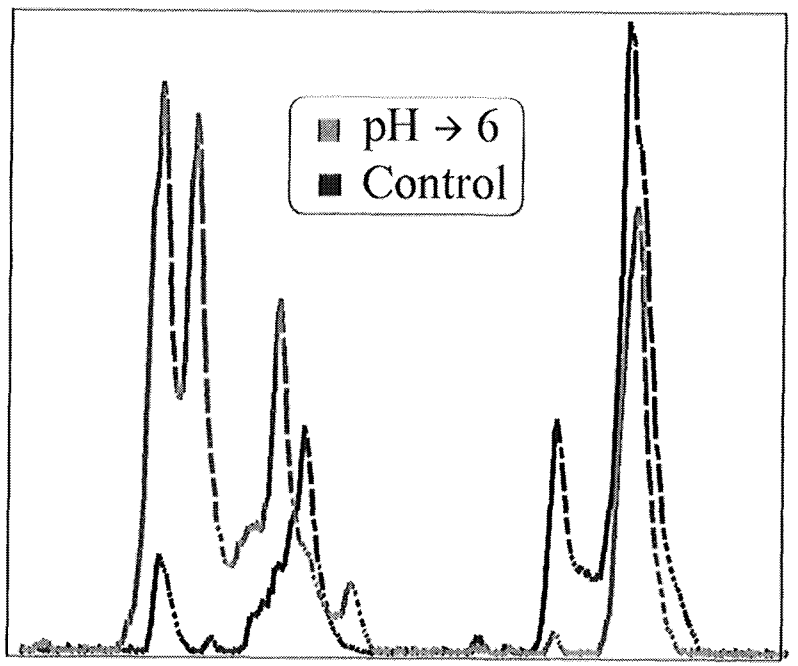


Functional Dynamics of a Complex Microbial Community as indicated by 16S rRNA finger-printing

Molecular approach to answer the question :

Who *is doing* ***What*** *?*

rDNA ***rRNA***



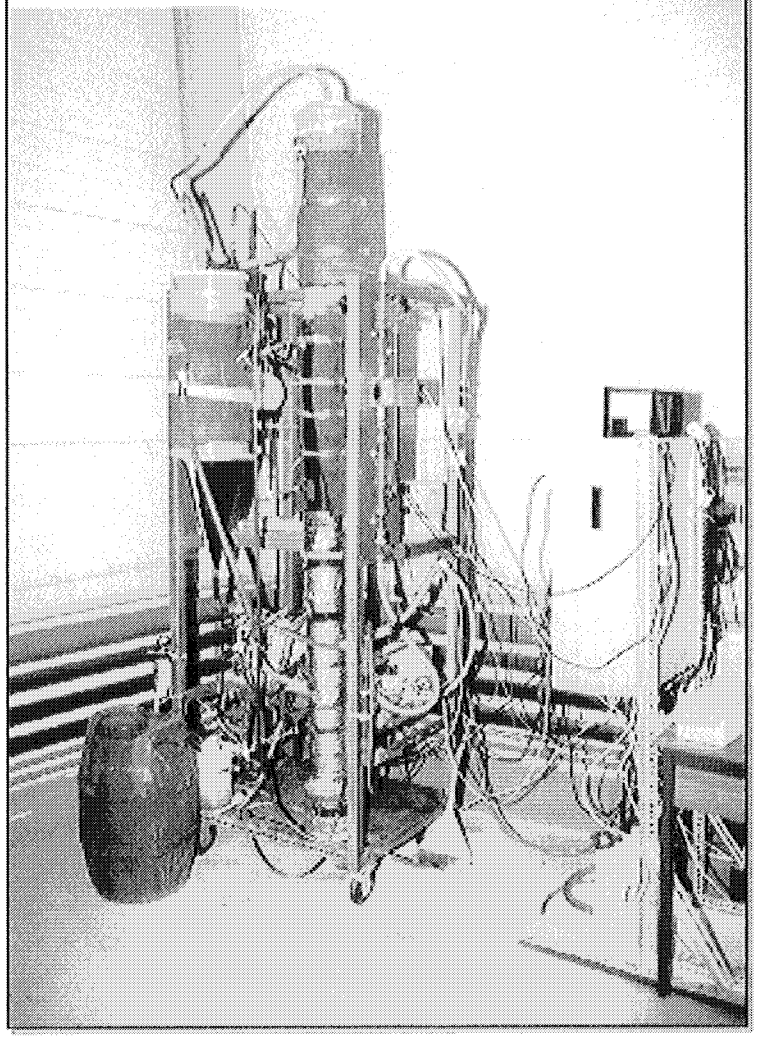
Effect of an acidic shock (pH : 7 → 6) on the activity of the different species

- ✓ Species can be identified by cloning and sequencing the 16S rDNA genes
- ✓ A peak = one species
- ✓ Area of a peak ≈ activity of the corresponding species

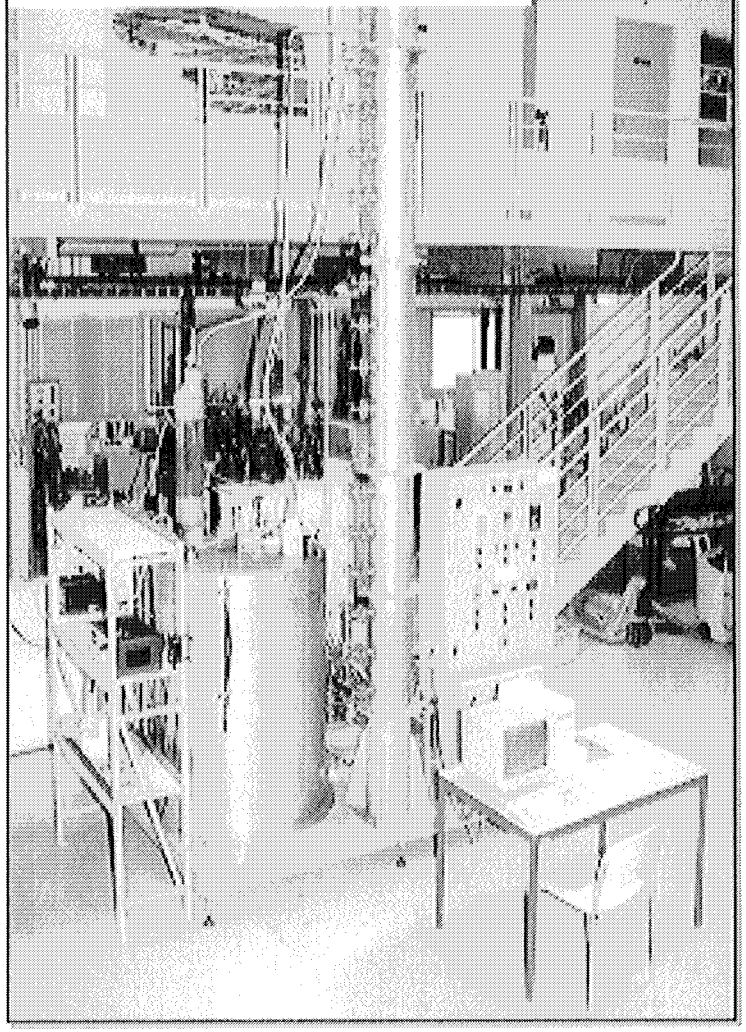
Examples of AD Processes in Narbonne

· *Fluidized Bed Reactors* · *Effluent : Industrial distillery vinasses*

15 liters working volume



150 liters working volume

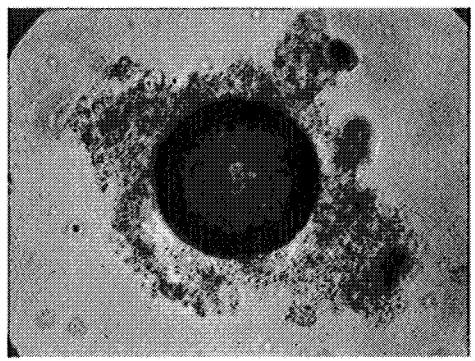


Analysis of Biofilms

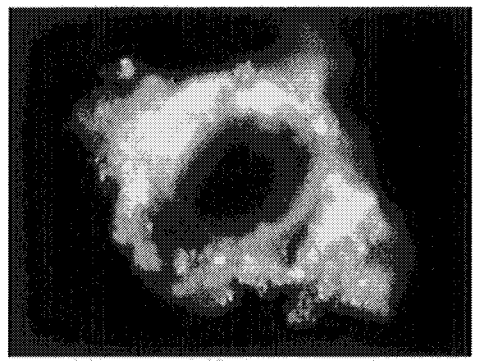
General objective : To study and to improve the kinetics of biofilm development on granular carriers

One way : Image Analysis

Example of qualitative analysis using DAPI coloration for fluidized bed reactor



Normal light



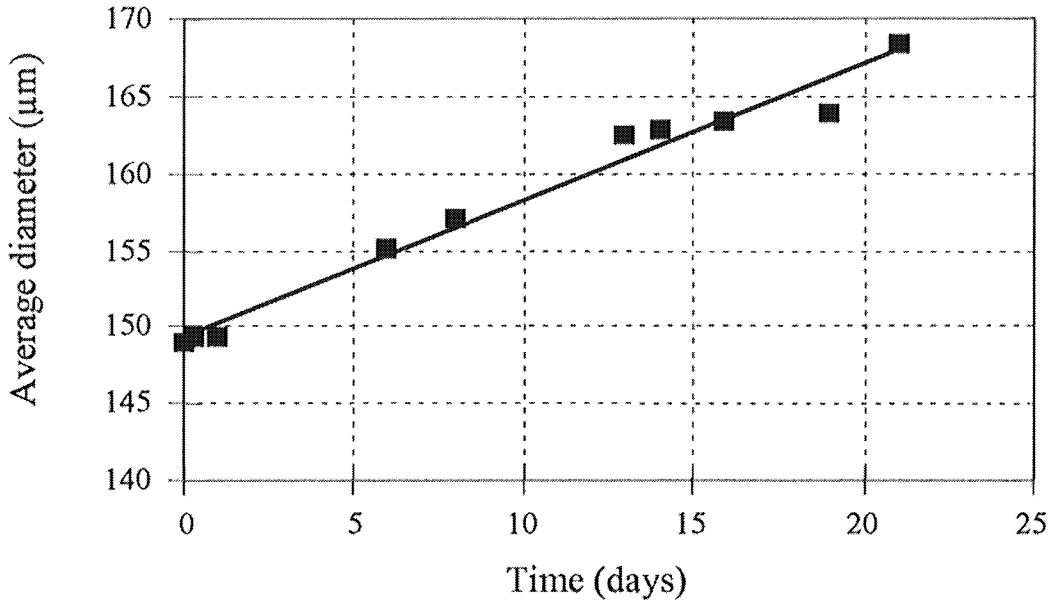
UV fluorescence

Analysis of Biofilms

Based on the previous results,
quantitative measurement of biofilm growth

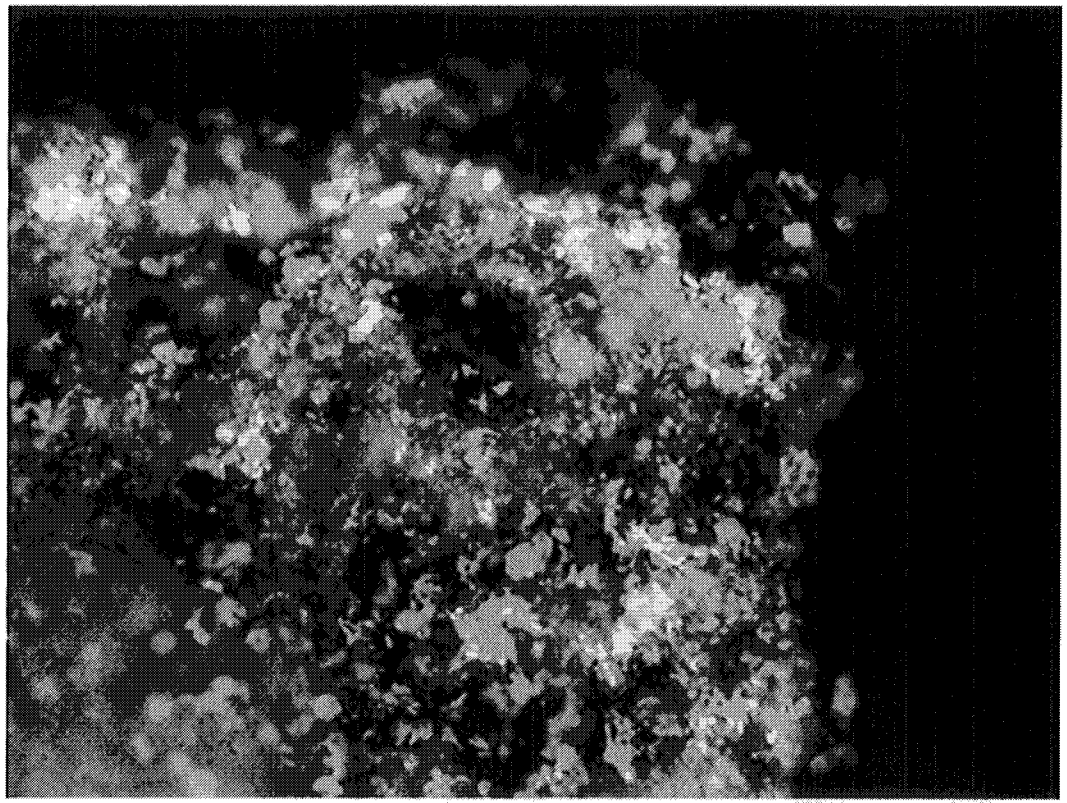
↳ For example, estimation of
equivalent diameters and ***shape factors***

Example: biofilm growth in an anaerobic biofilm reactor : evolution of particle size



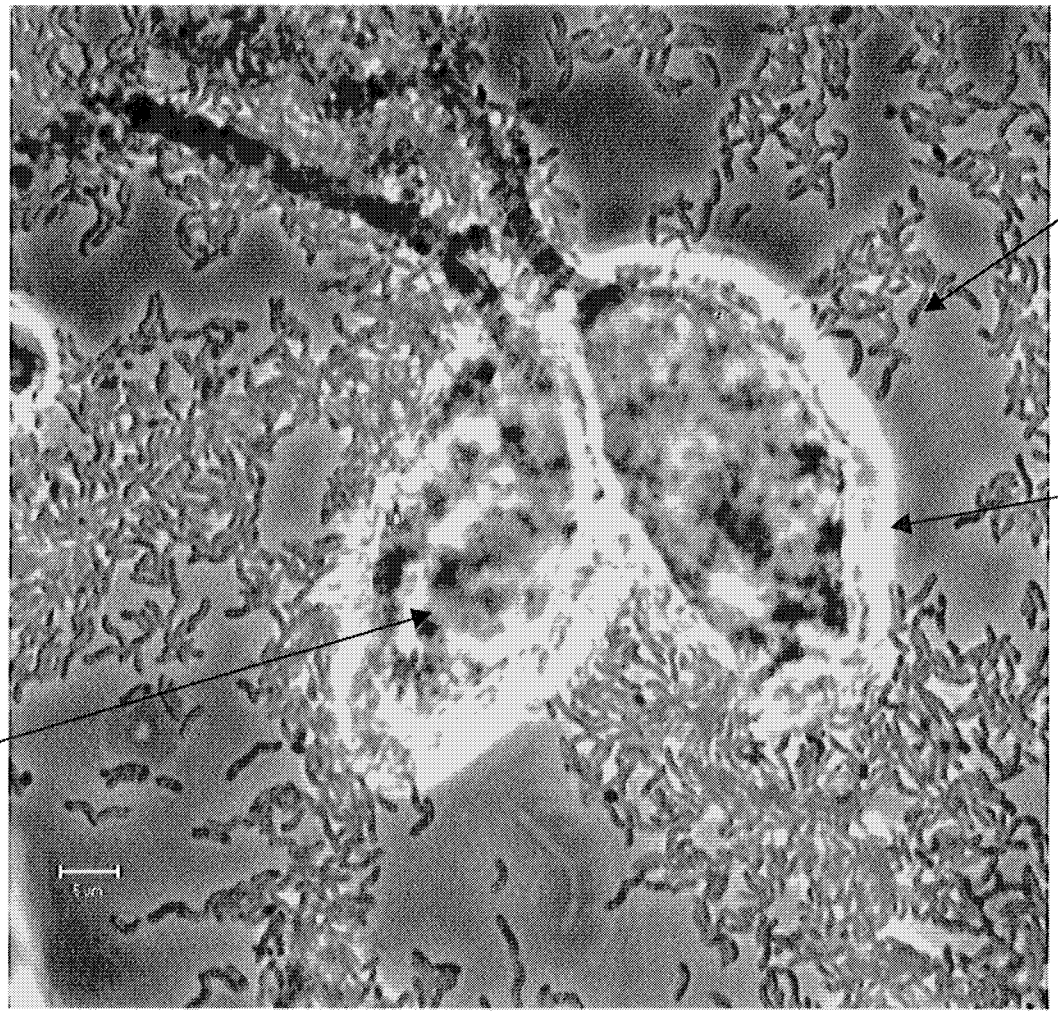
If you get closer ...

Fluorescent In Situ Hybridization (FISH)



Blue : All species Red : One specific bacteria

Life is sometimes difficult for bacteria ...

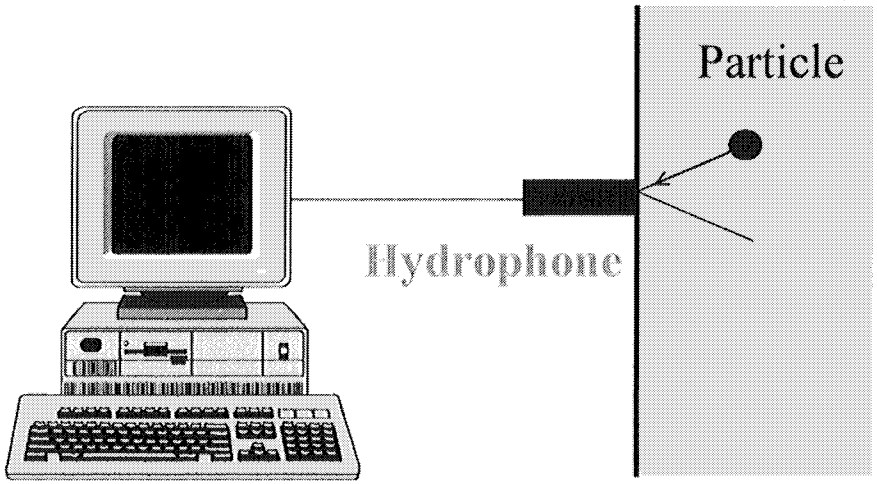


Microvirgula aerodenetrificans

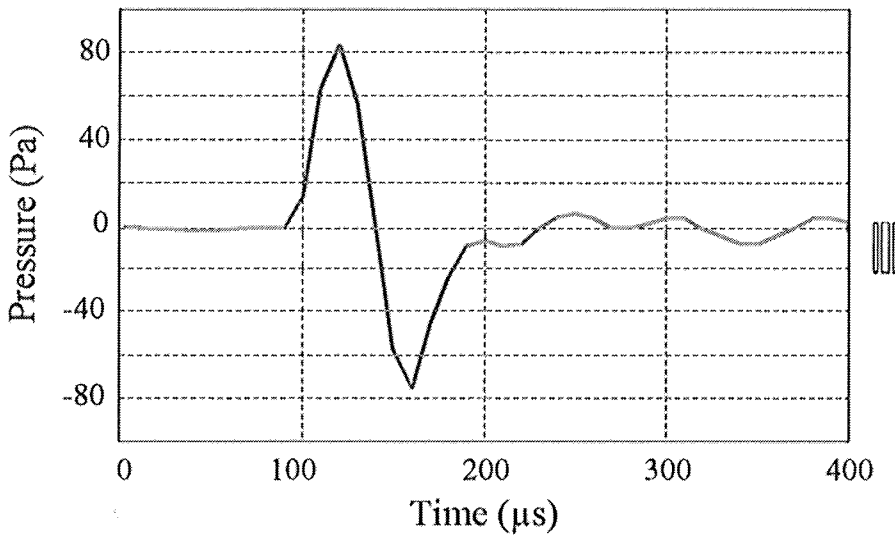
Protozoa

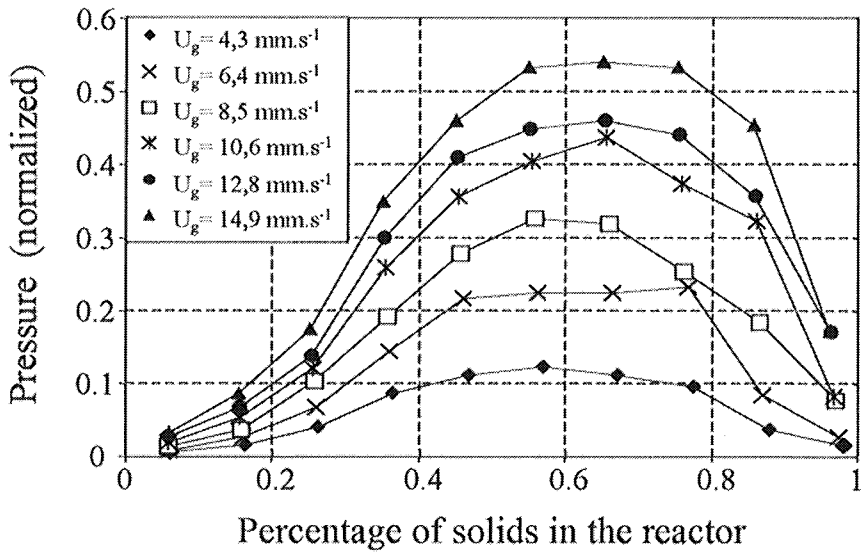
"Stomach" of the protozoa

Sound can also help to understand hydrodynamics



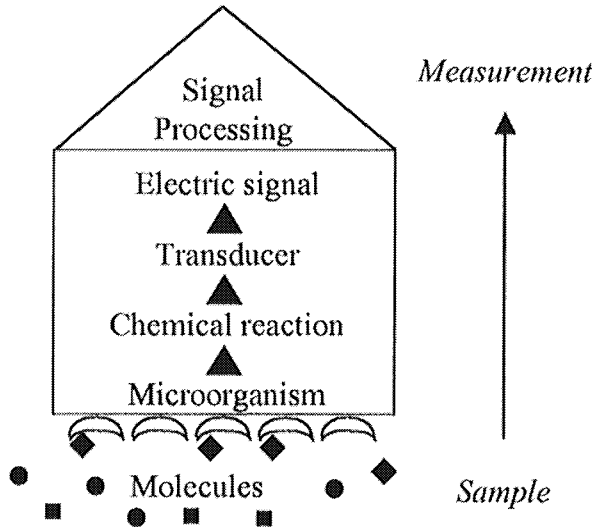
Design Parameters for the Process



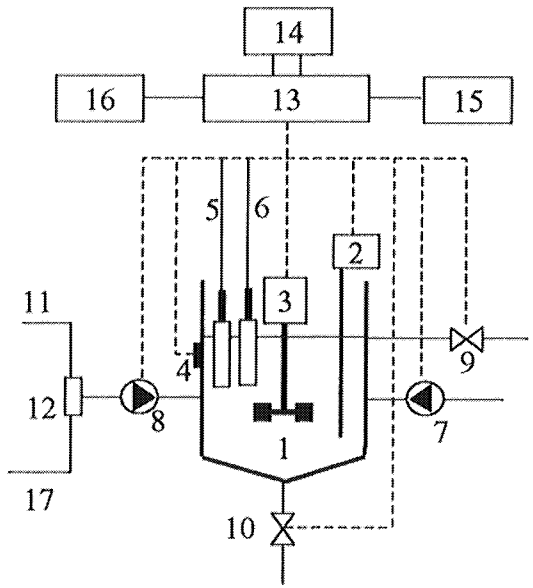


Examples of advanced sensors

1) Biosensor
(e.g., biological reaction directly in a probe)



2) In-situ sensor
(e.g., respirometric sensor)



1. Reactor (10 cm^3 sludge)
2. Aerator
3. Stirrer
4. Temperature sensor
5. DO electrode
6. pH electrode
7. Calibration pump
8. Sample pump
9. Decantation valve
10. Sludge outlet valve
11. Bypass
12. Filter system (0.5 mm)
13. Microprocessor
14. Display/keyboard
15. Computer (PC)
16. Printer
17. Wastewater

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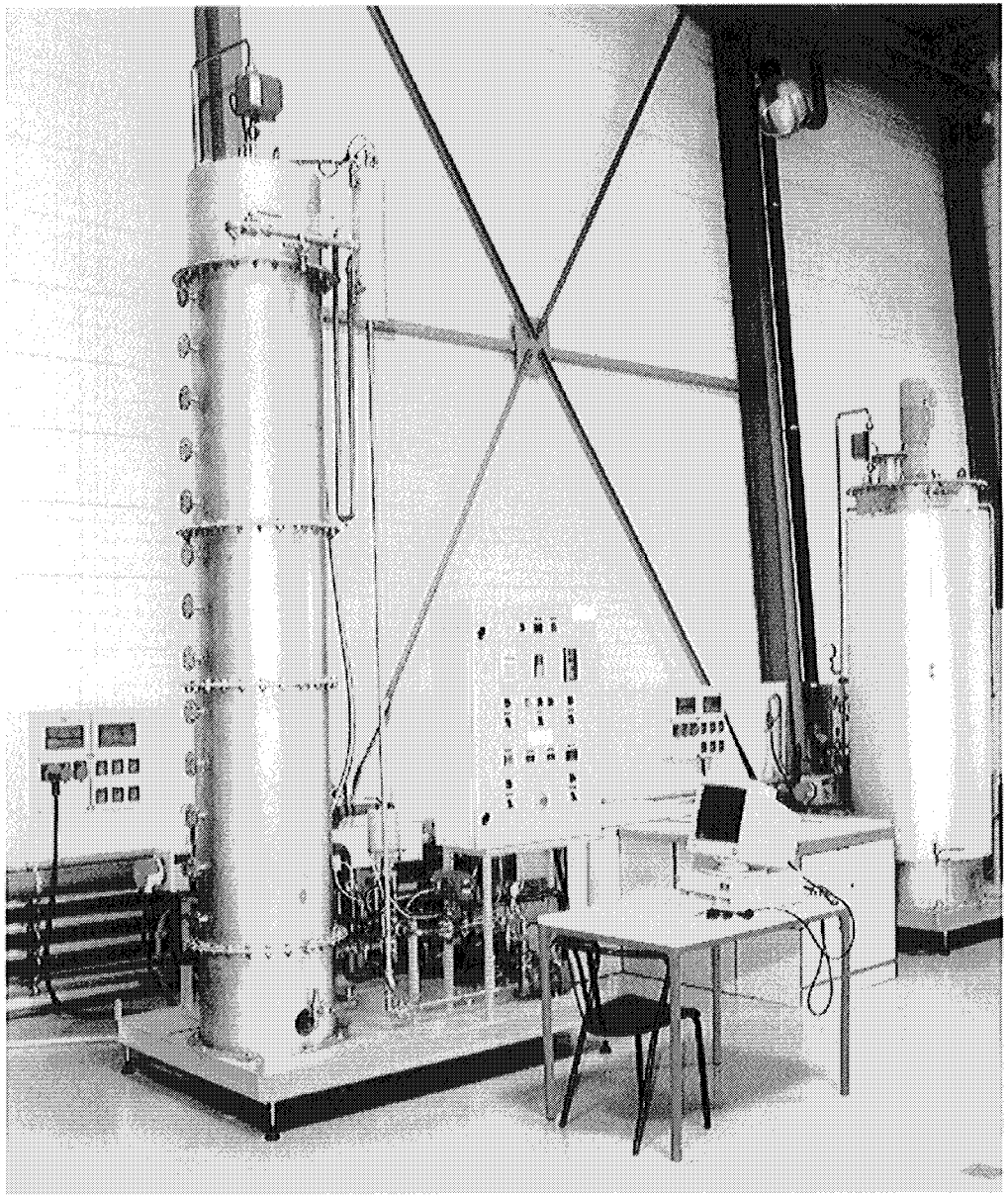
The process used

Influent : **Raw industrial distillery vinasses**

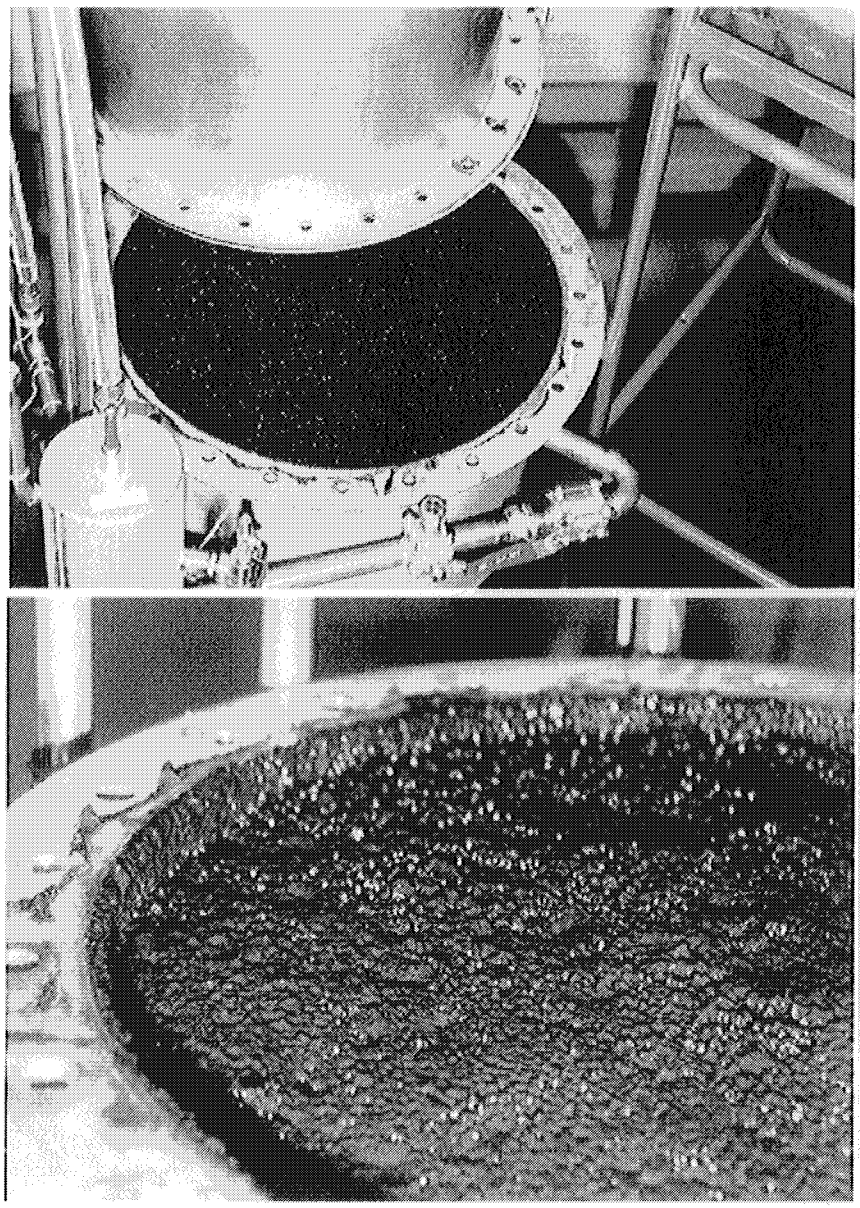
Reactor : **Circular column**
Up-flow fixed bed reactor
- 3.5 m height,
- 0.6 m diameter,
- 982 liters of total volume.

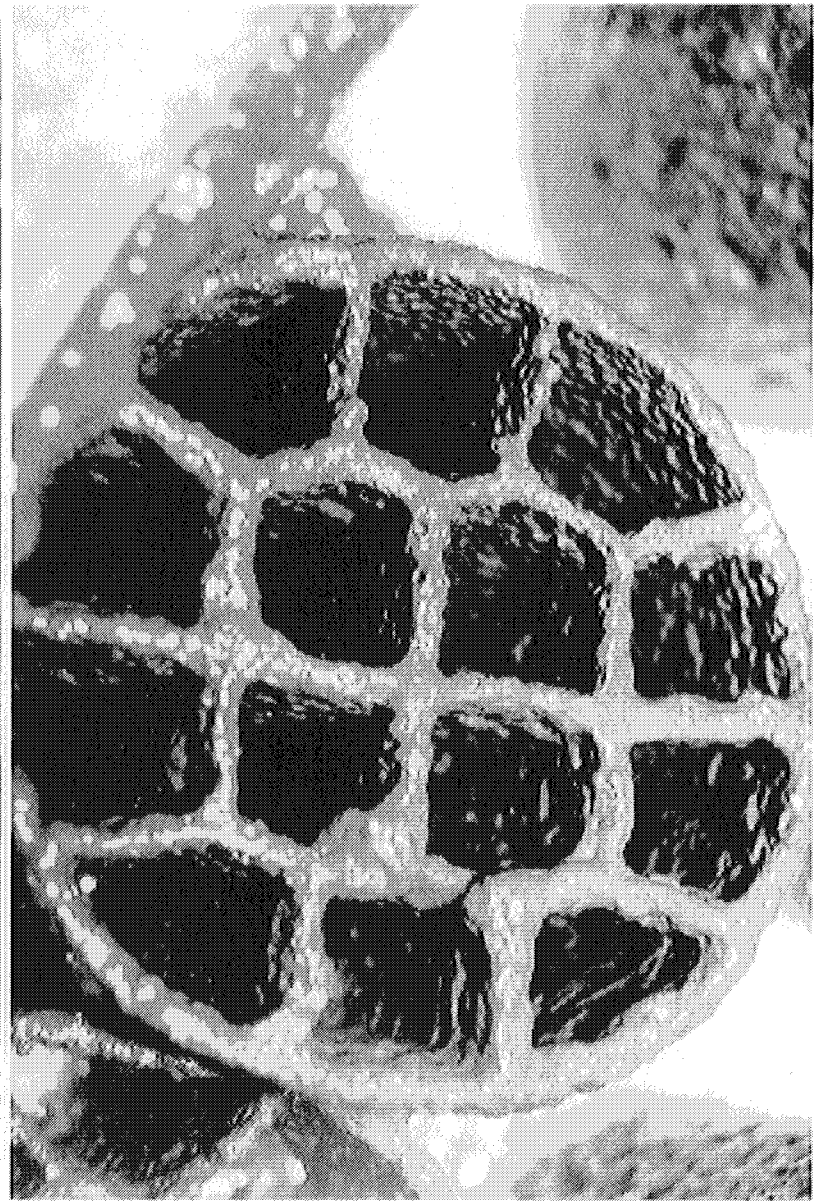
Media : **Cloisonyl**
- Specific surf. : 180 m^2/m^3
- Volume : 33.7 liters

Total effective volume : **948 liters**

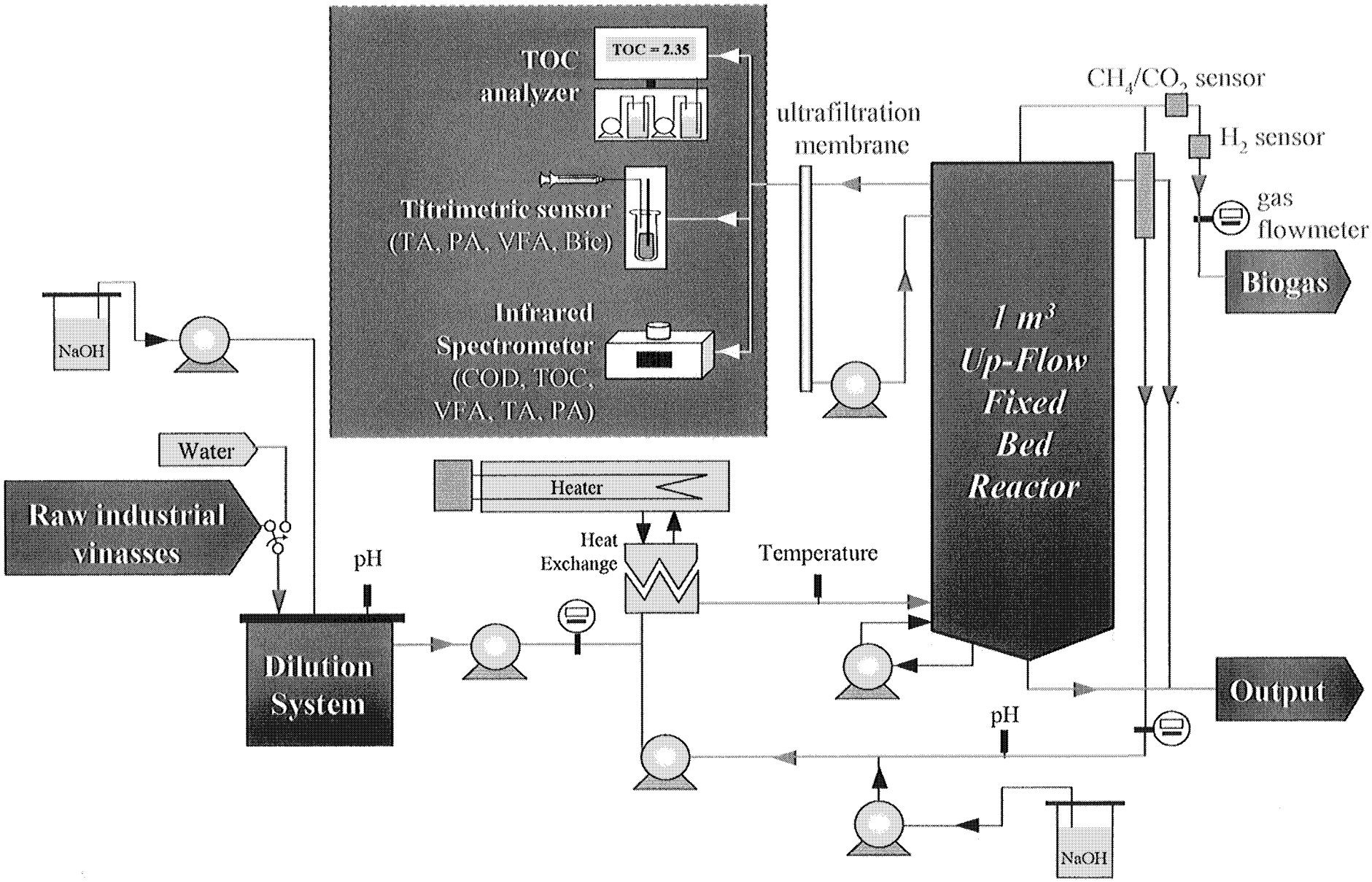


Media for Microorganisms (Cloisonyl)

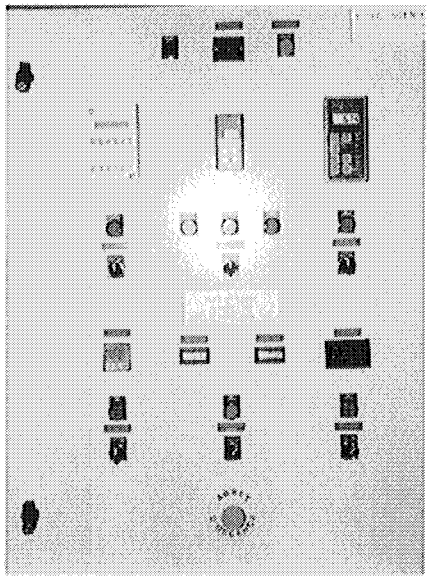




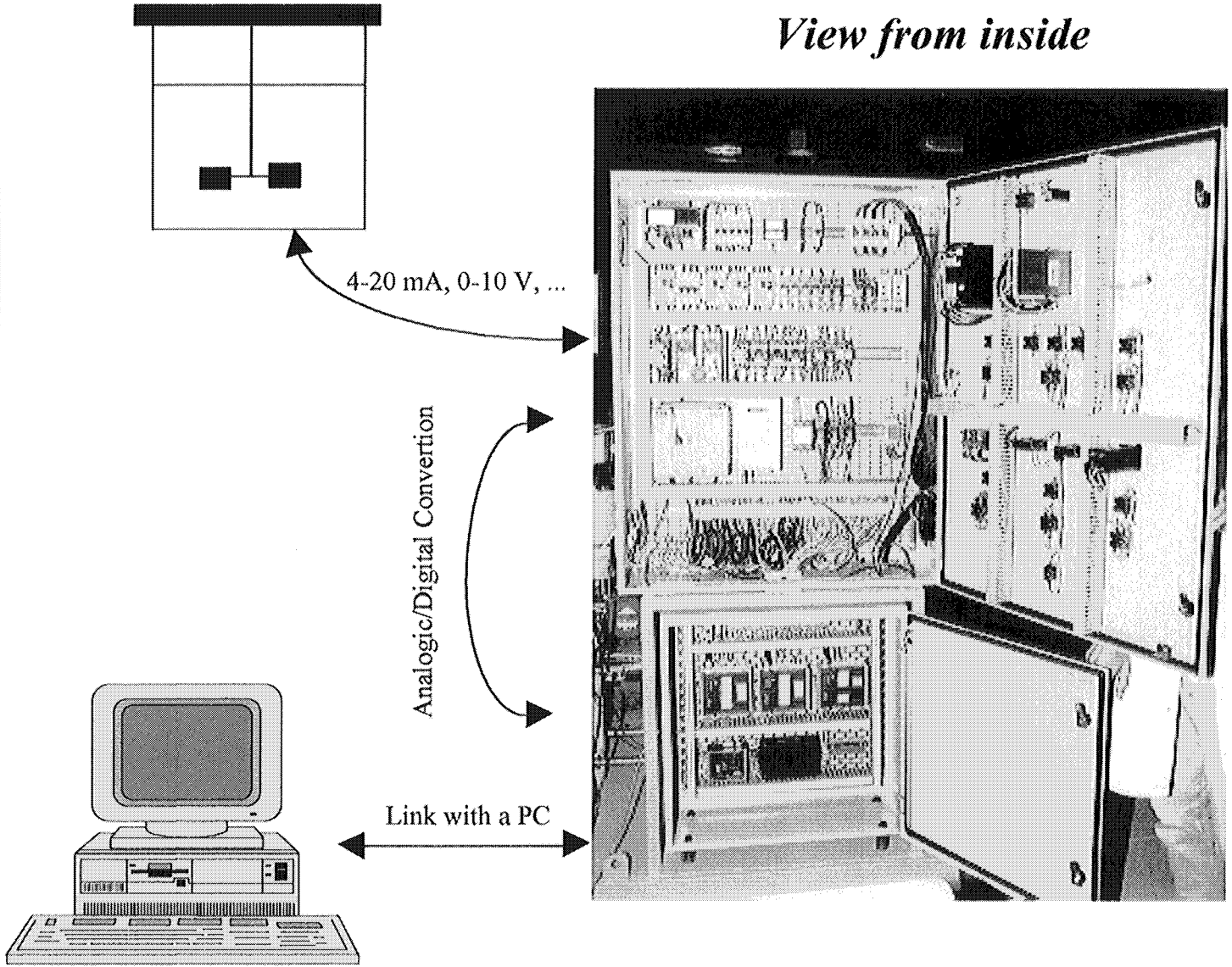
Schematic layout of the plant



The Input/Output Device

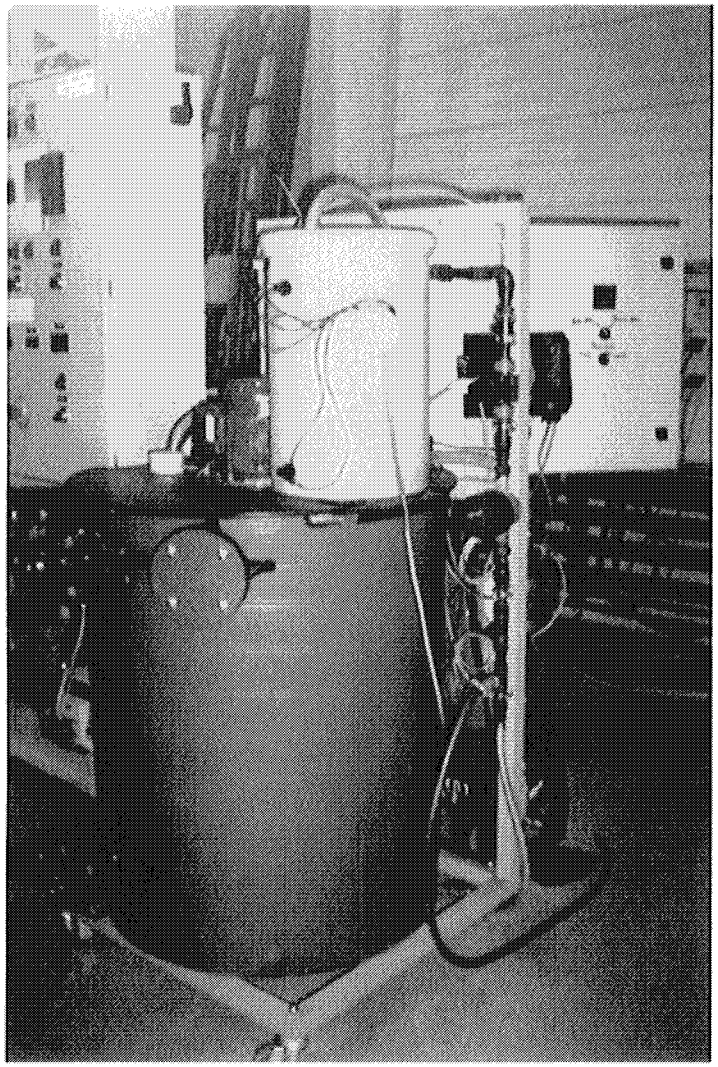


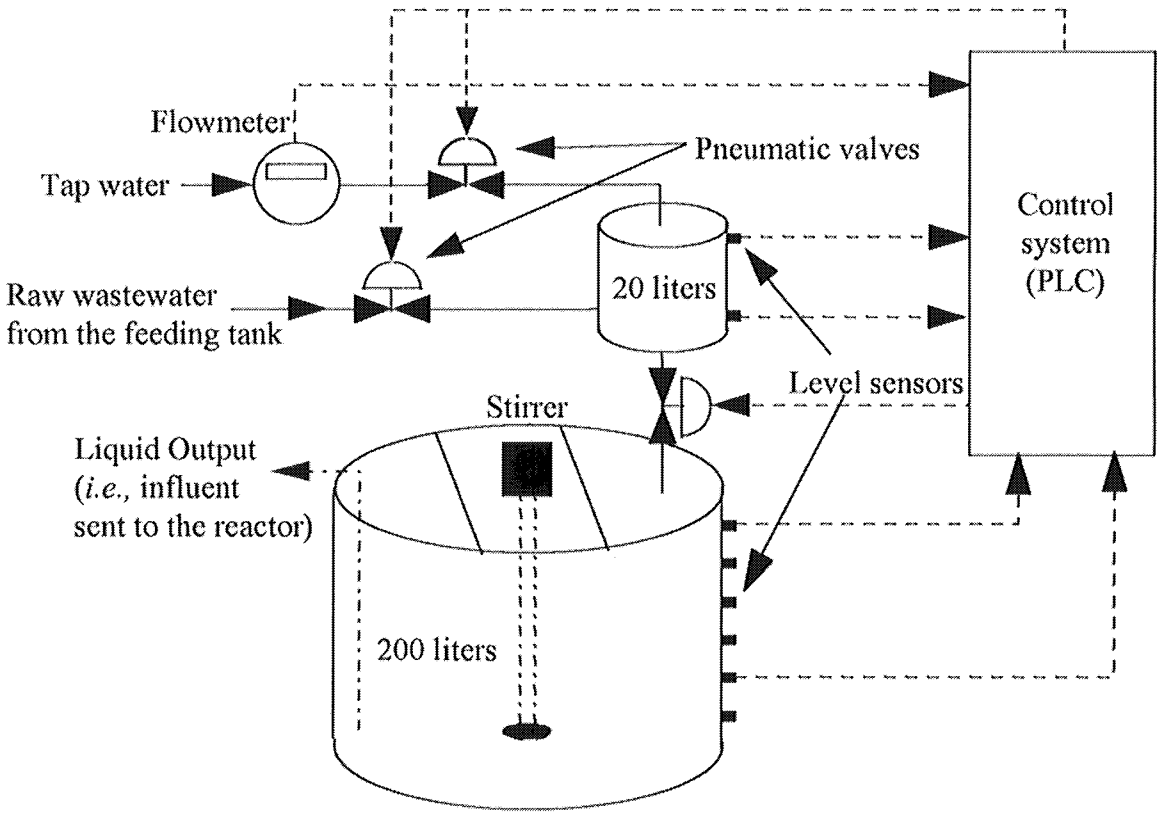
View from outside



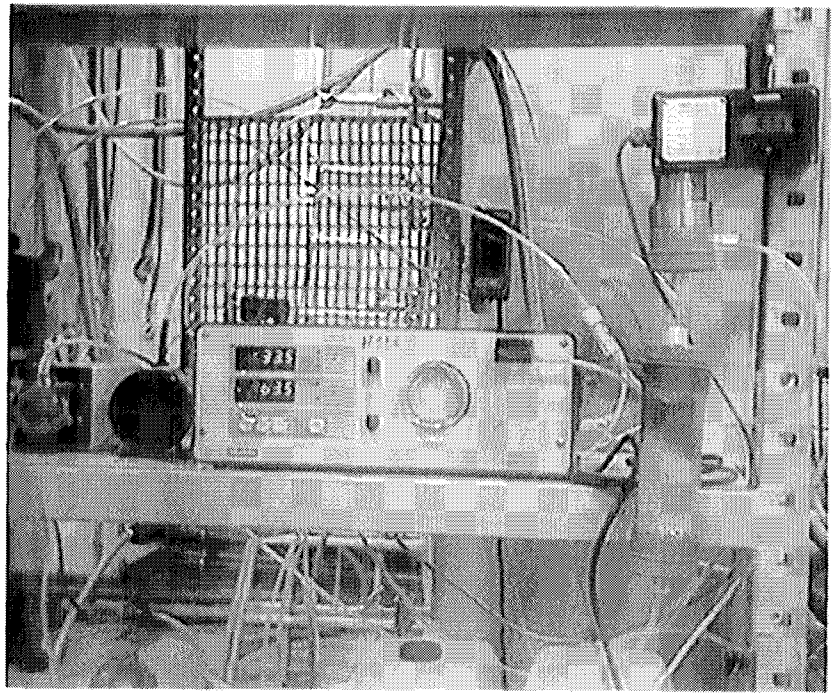
View from inside

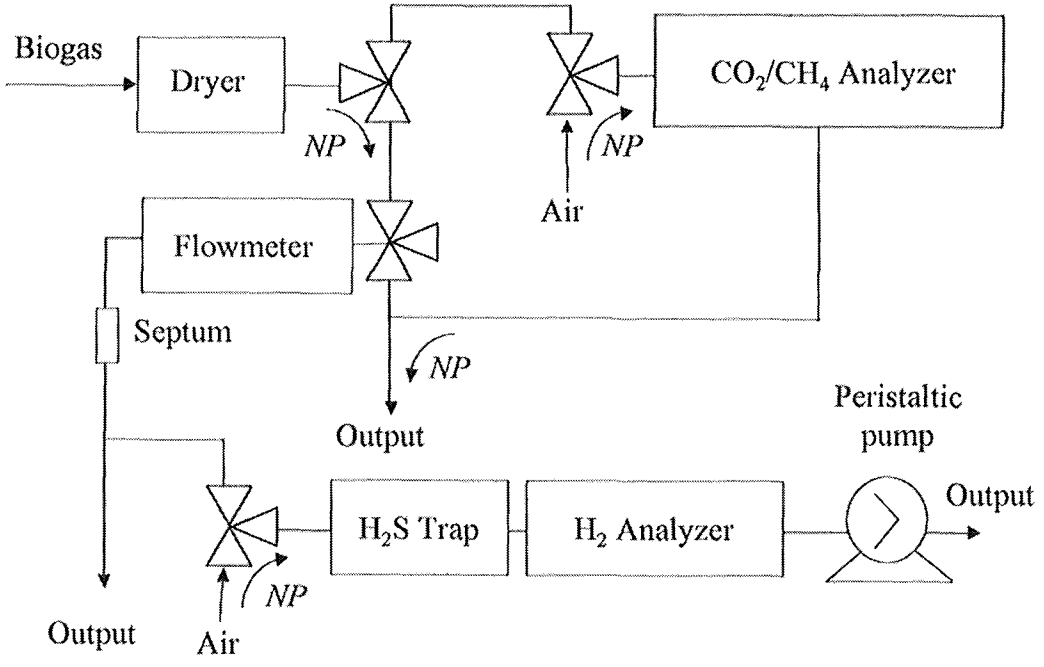
The Dilution System



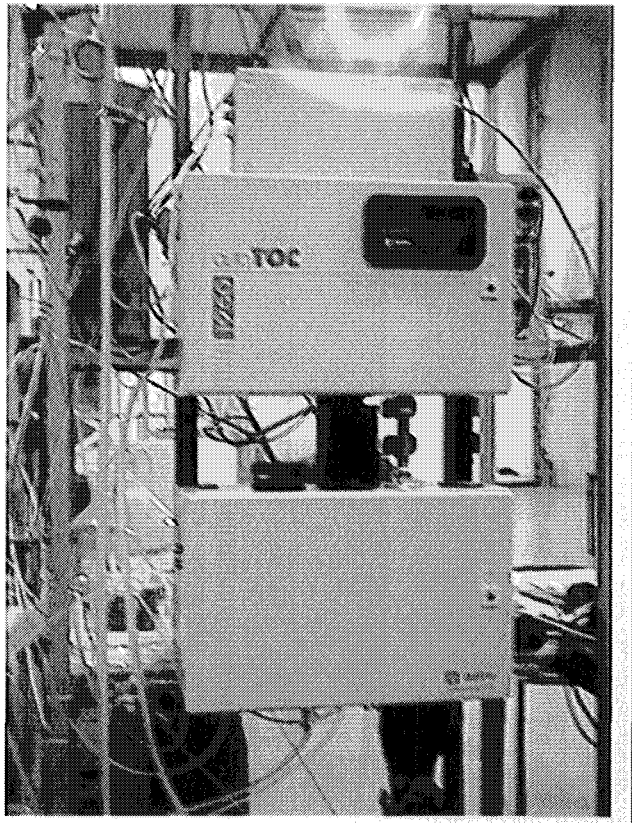


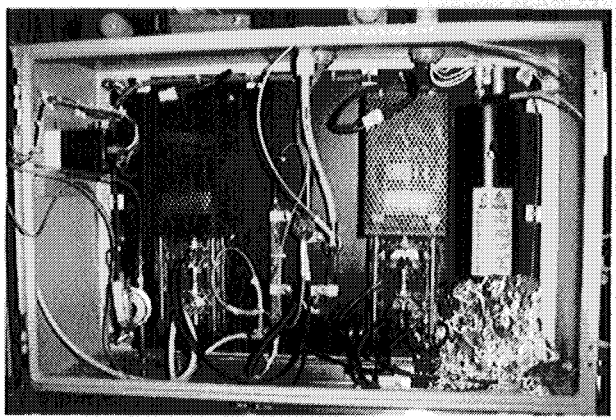
The Gaz Analyzing Loop

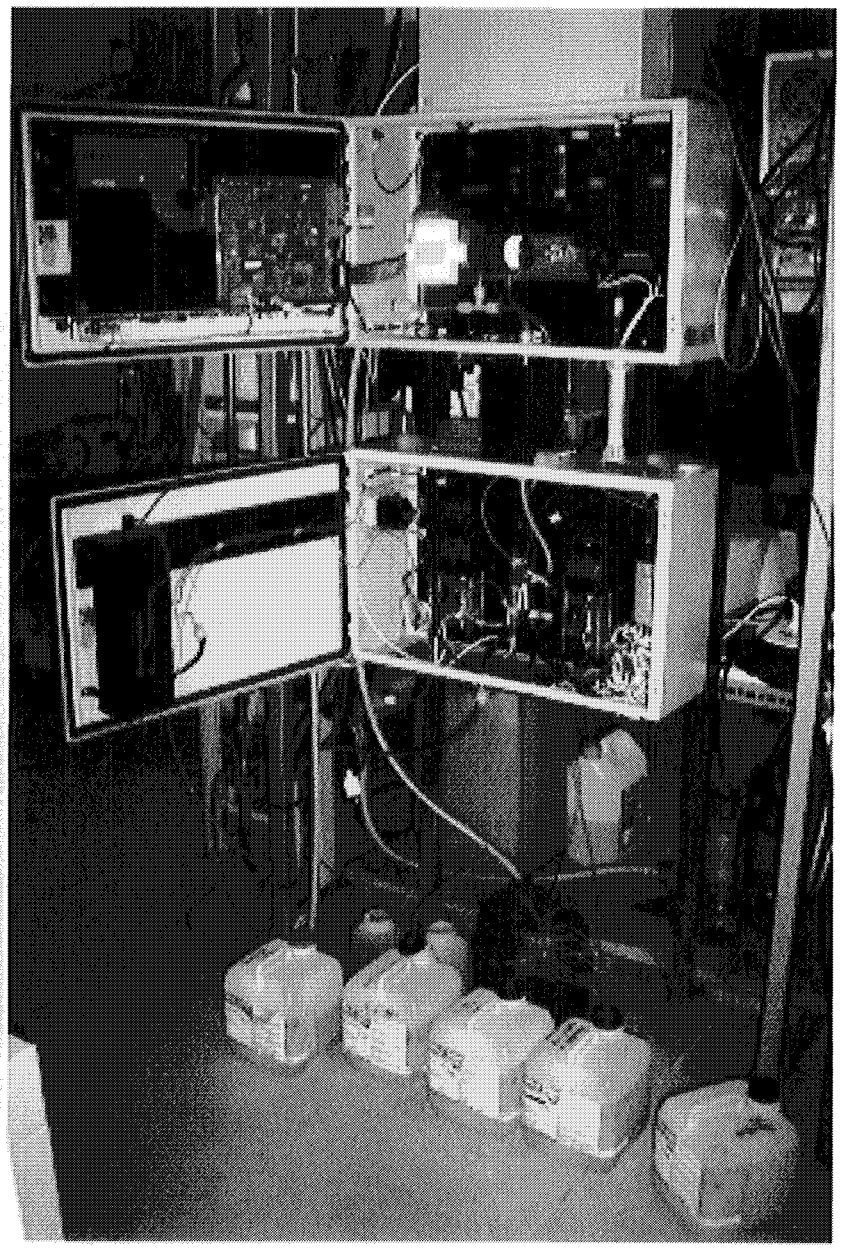




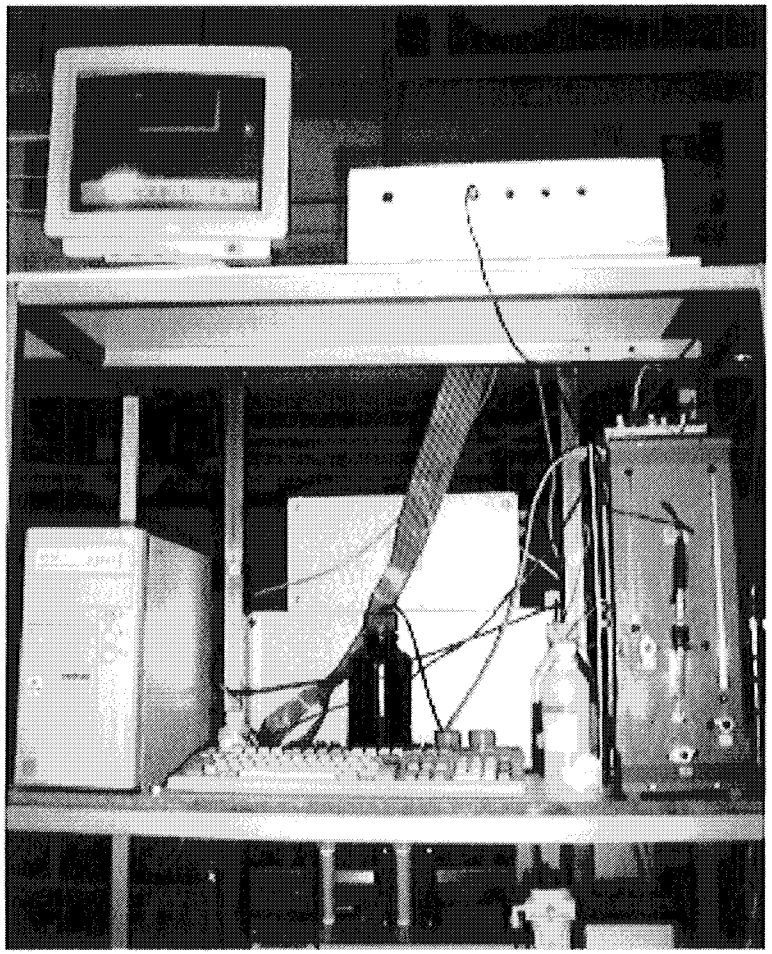
The TOCmeter





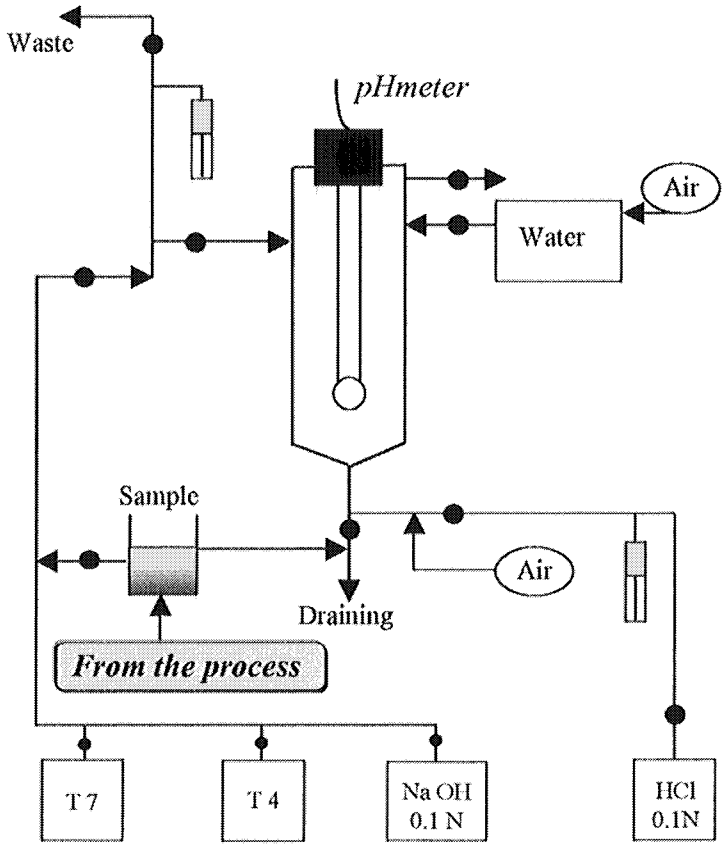


The Titrimetric Sensor



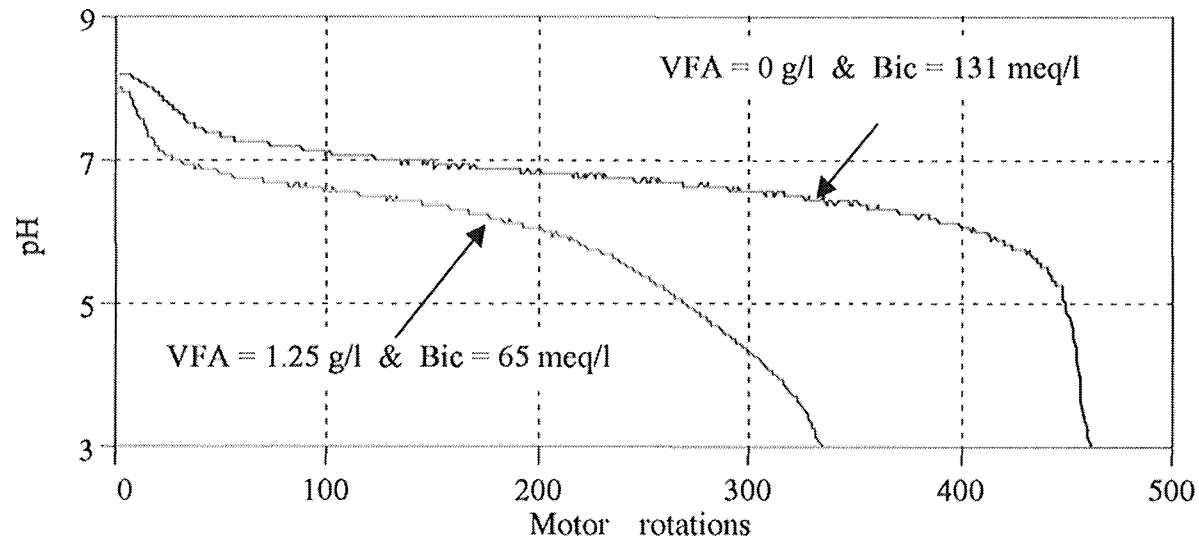
Sensor for On-Line Automated Titration

- ✓ Measurements of Partial and Total Alkalinity,
- ✓ Estimations of Bic and VFA concentrations

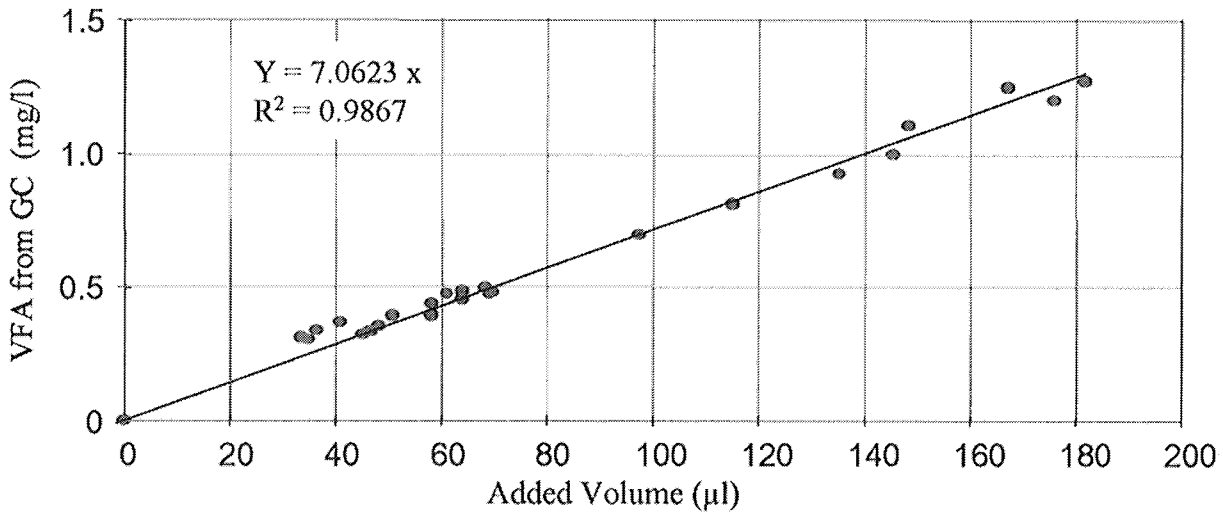


The Titrimetric Sensor

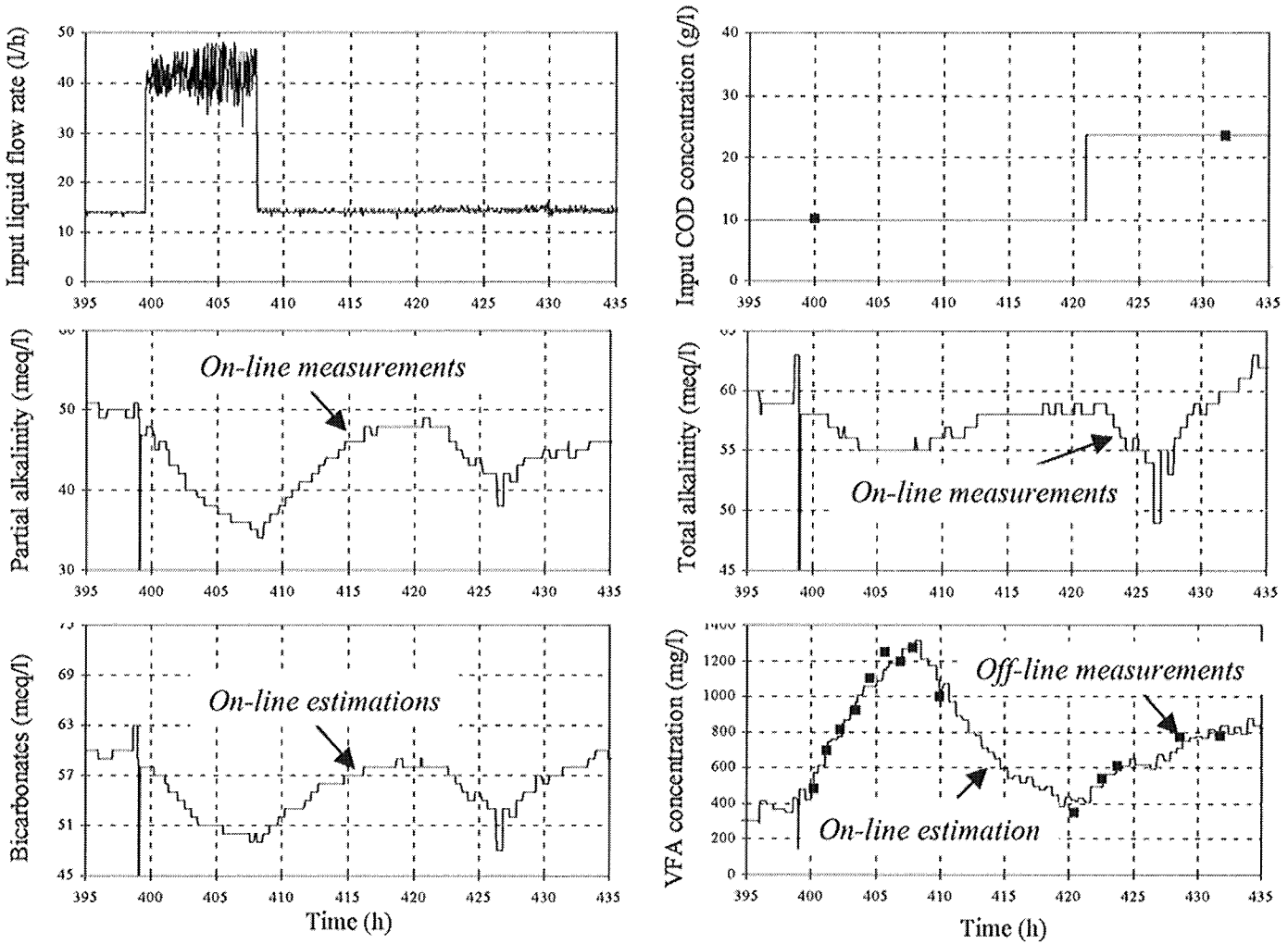
Titration curves



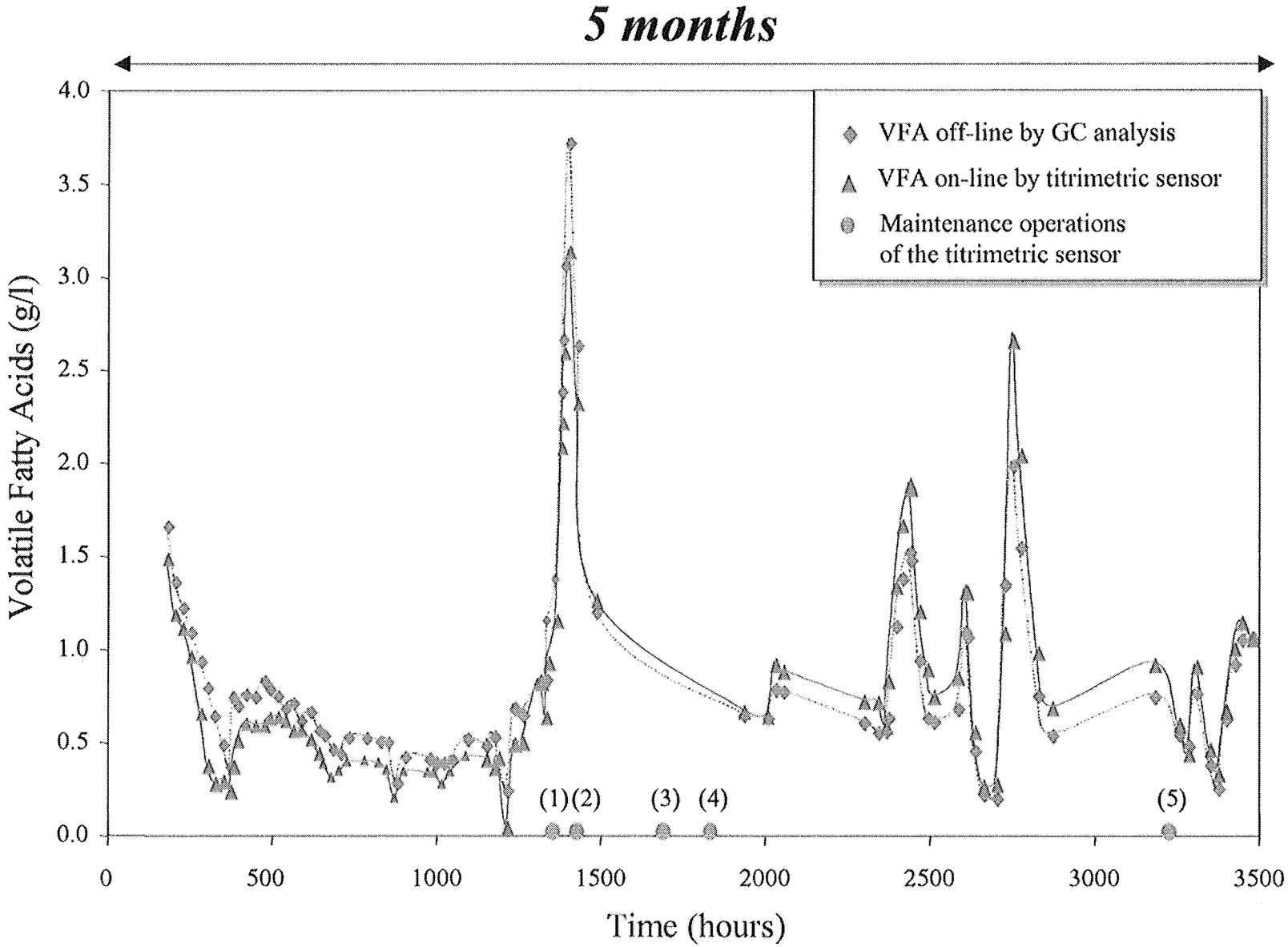
Senssor Validation



Titrimetric Sensor : On-line Results

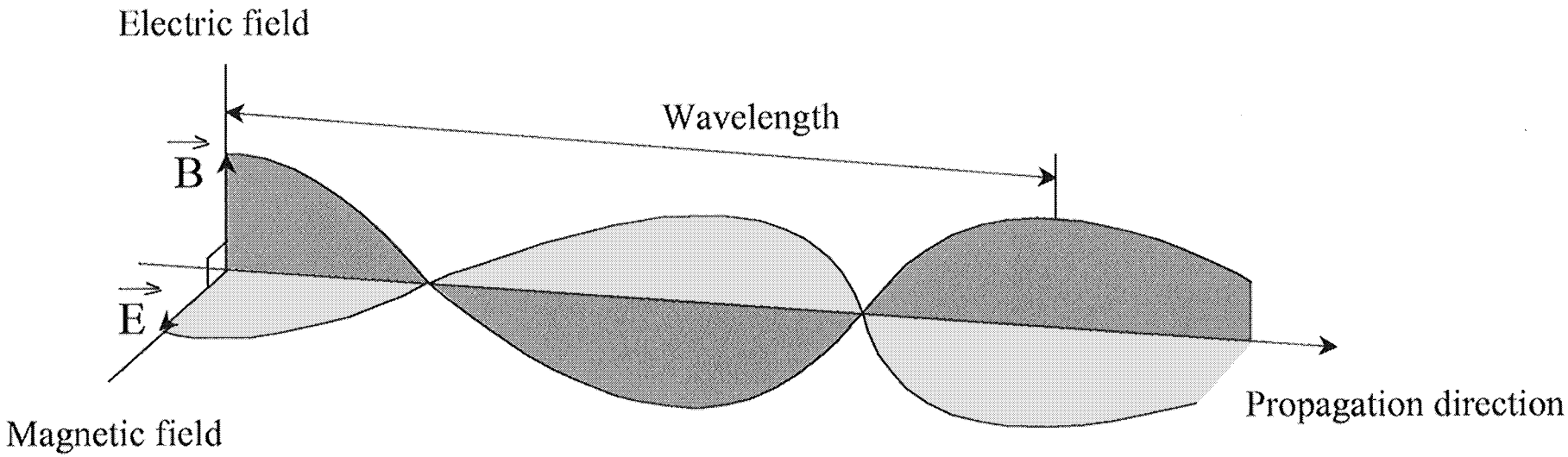


Titrimetric Sensor : On-line Results



The Mid InfraRed Spectrometer

Electromagnetic wave : Some Vocabulary



Wavelength	:	λ	($\mu m = 10^{-6}$ m , nm = 10^{-9} m)
Wavenumber	:	$\nu = 1/\lambda$	(cm^{-1})
Frequency	:	$f = C/\lambda$	(s^{-1})
Propagation speed in vacuum	:	$C = 3.10^{-8}$	($m.s^{-1}$)

Waves and Energy

Each electromagnetic wave conveys energy

If the wave has a frequency *f*,

it is associated to an energy quantum *E*

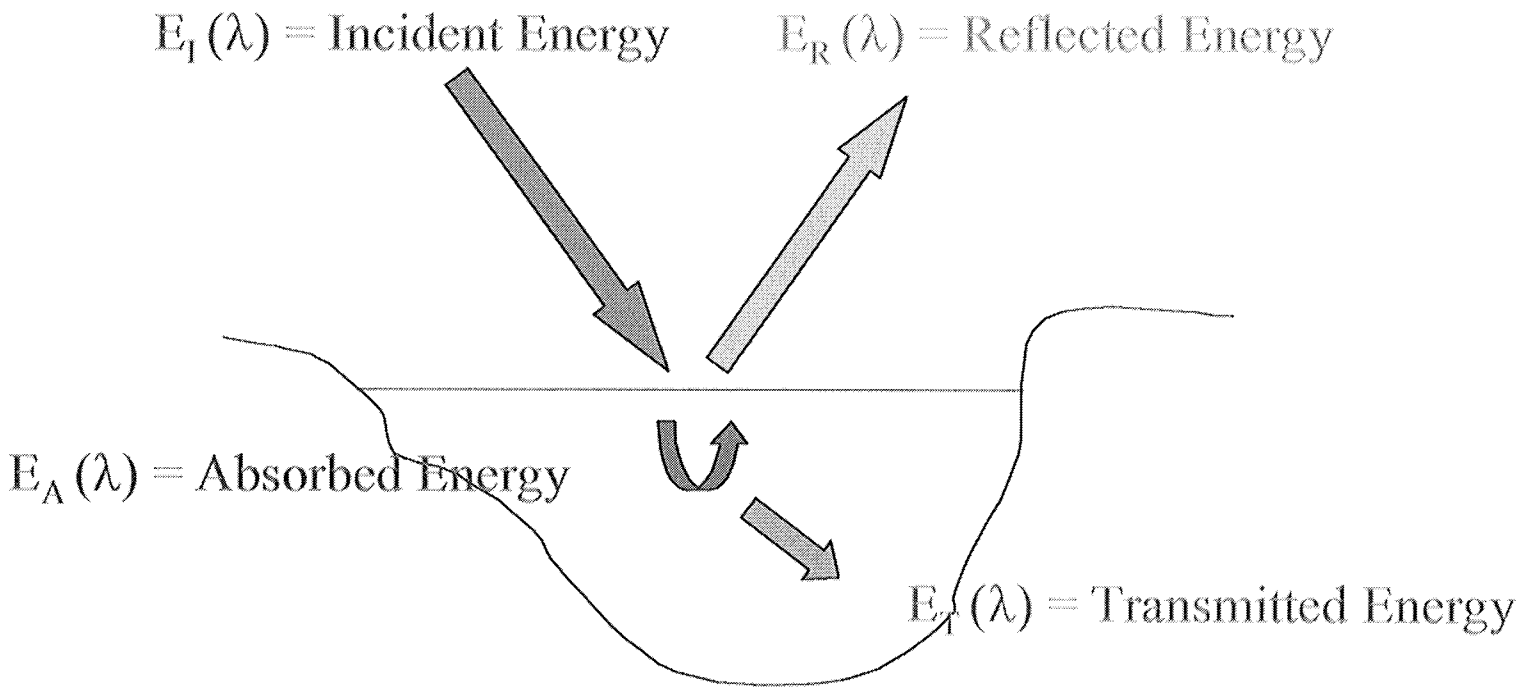
$$E = h \cdot f = h \cdot C / \lambda$$

With h : Planck constant ($6.62.10^{-34}$ J.s)

E : energy quantum in J

f : frequency in Hz

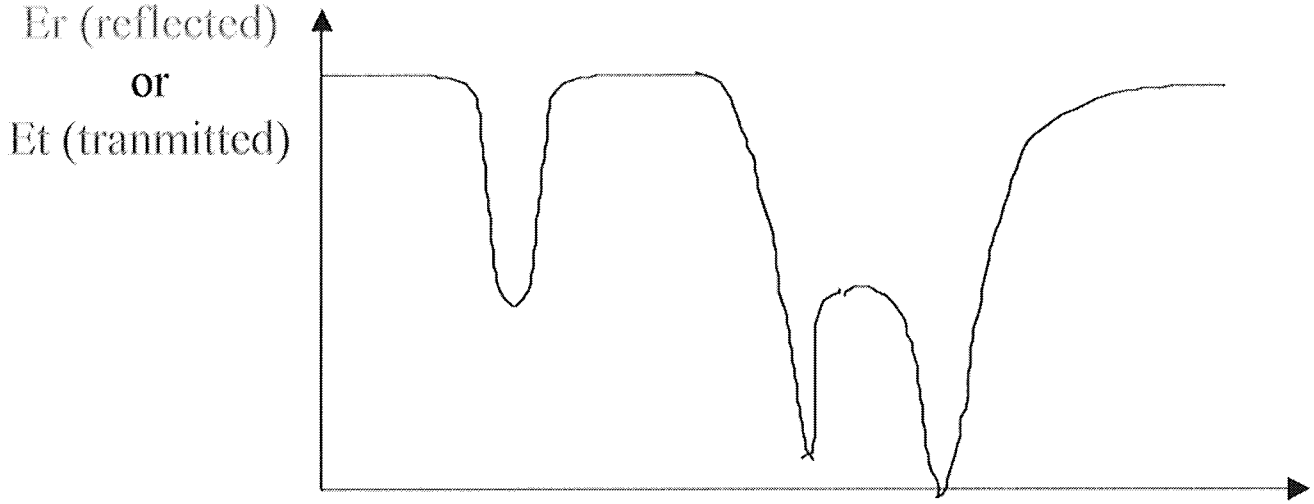
Energy conservation principle



Incident Energy = Reflected Energy + Absorbed Energy + Transmitted Energy

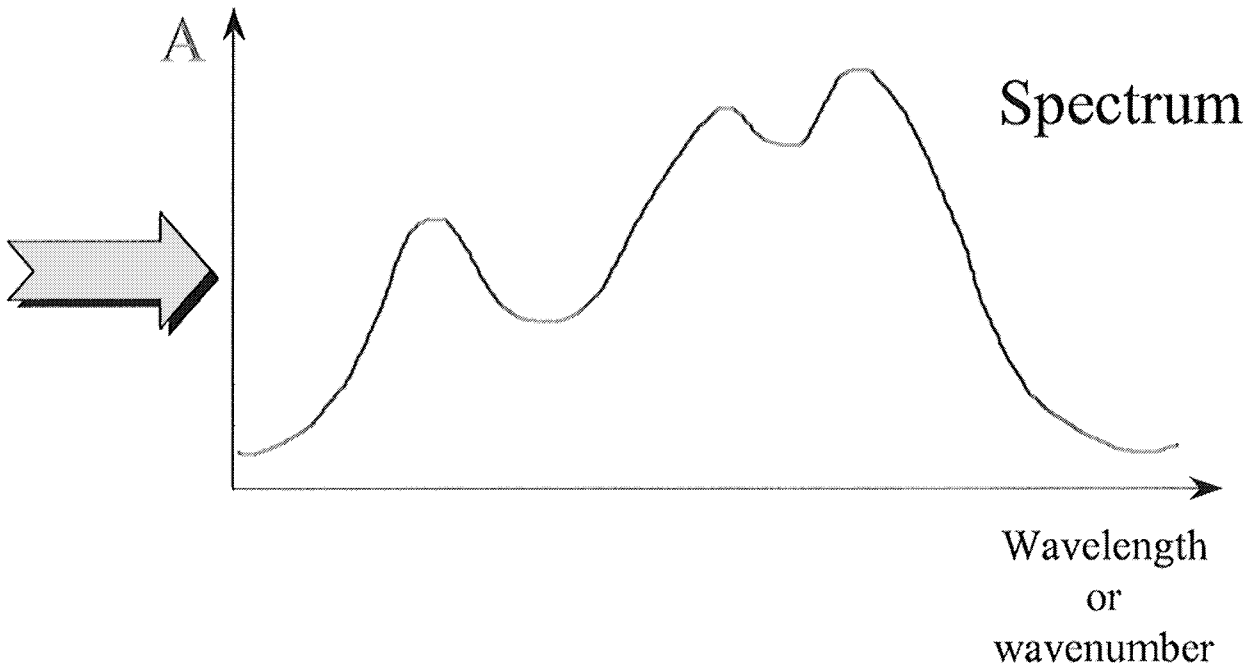
$$E_I(\lambda) = E_R(\lambda) + E_A(\lambda) + E_T(\lambda)$$

Waves and Matter

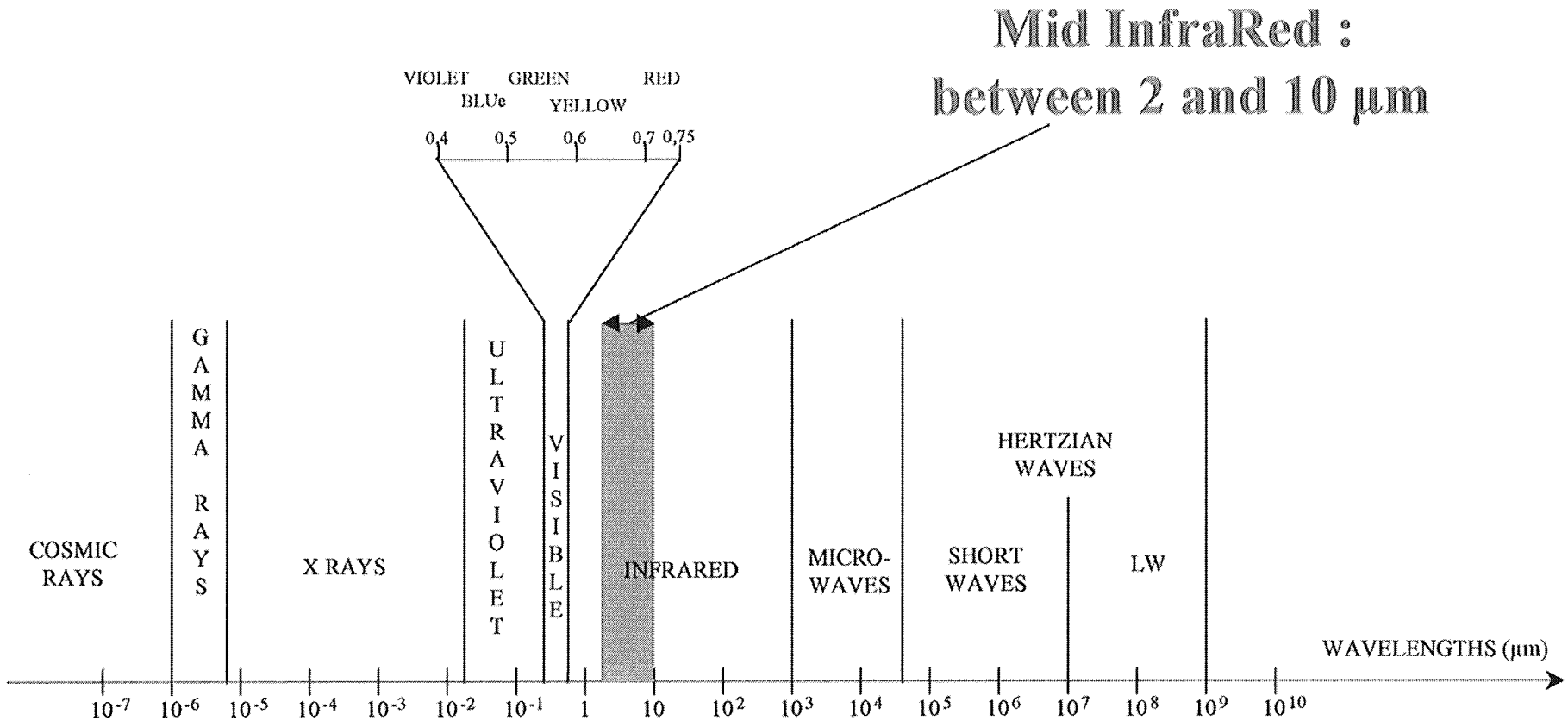


Transmission

$A = \text{Log}\,(E_T/E_o)$

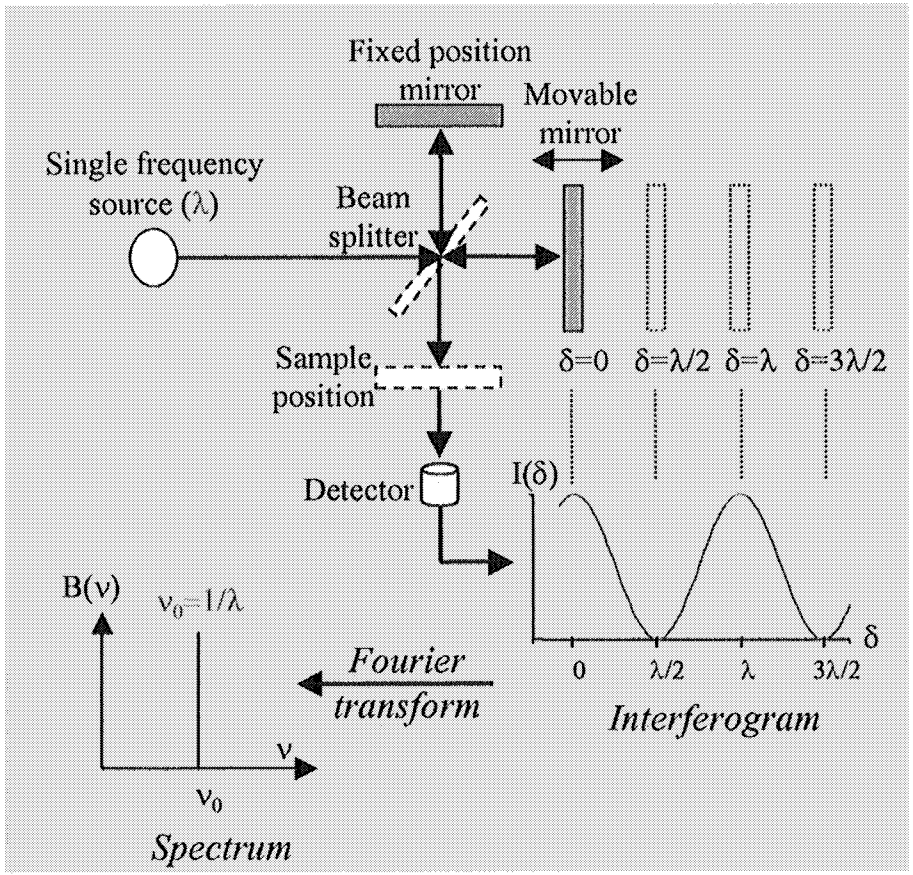


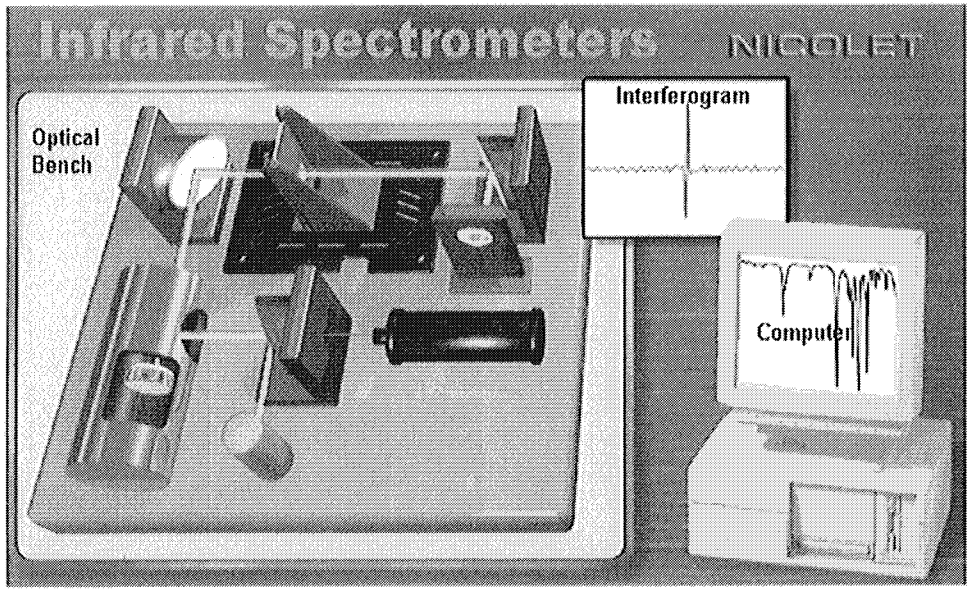
Wavelength in the Mid InfraRed



Principle of FT-IR Spectrometry

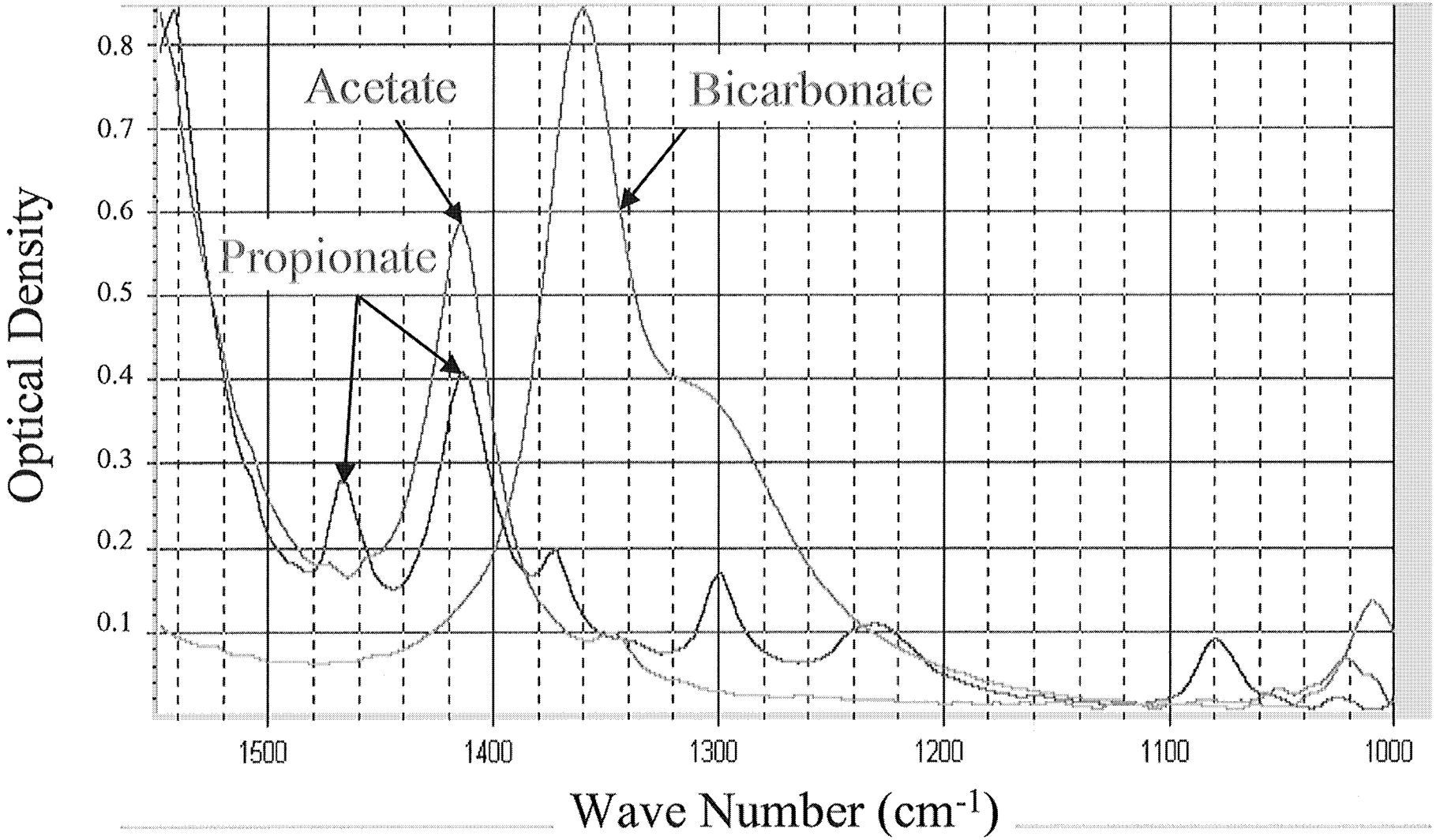
First interferometer : Michelson (1891)



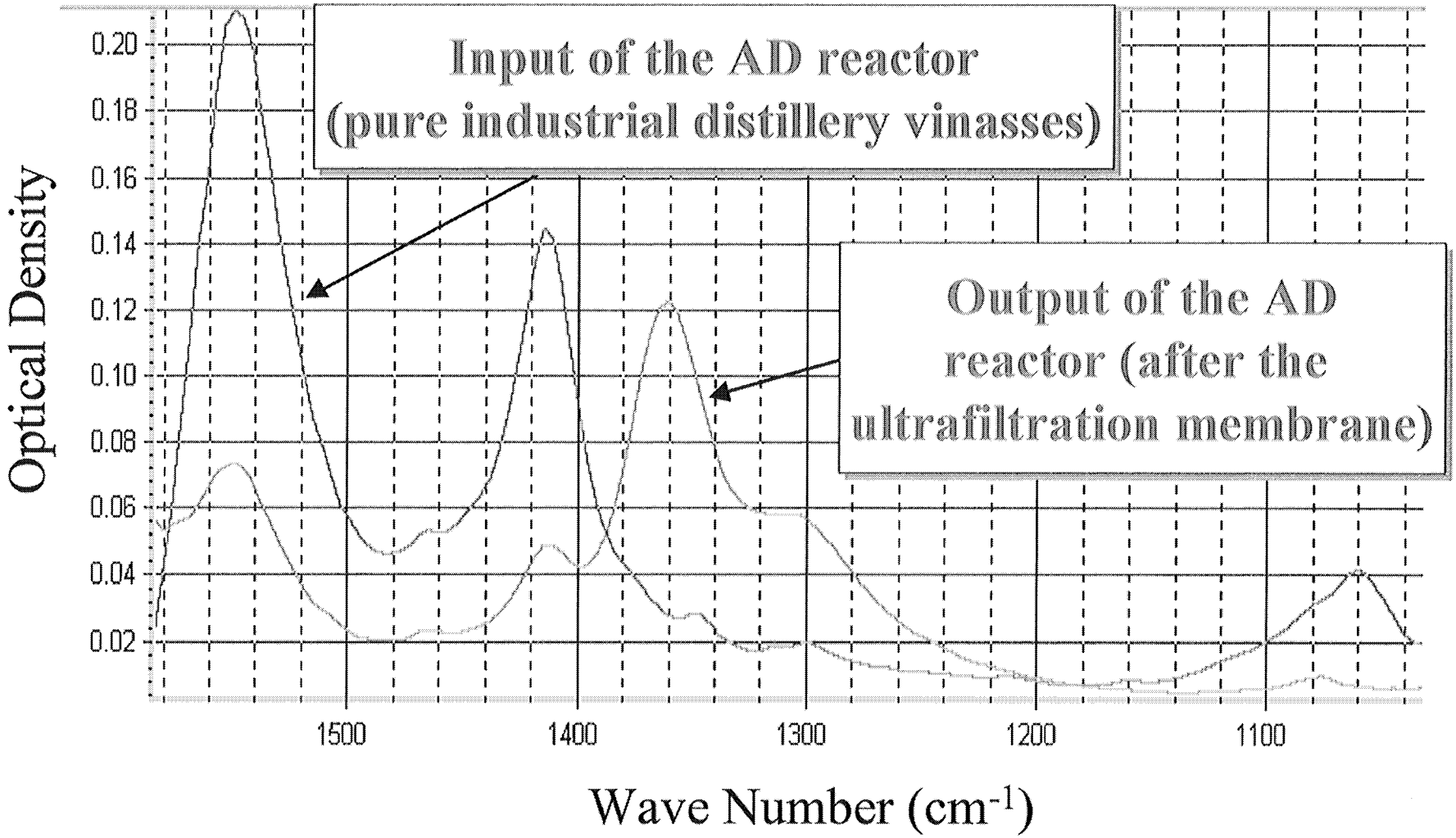


FT-IR : Fourier Transform Infra Red

Spectra of Pure Samples

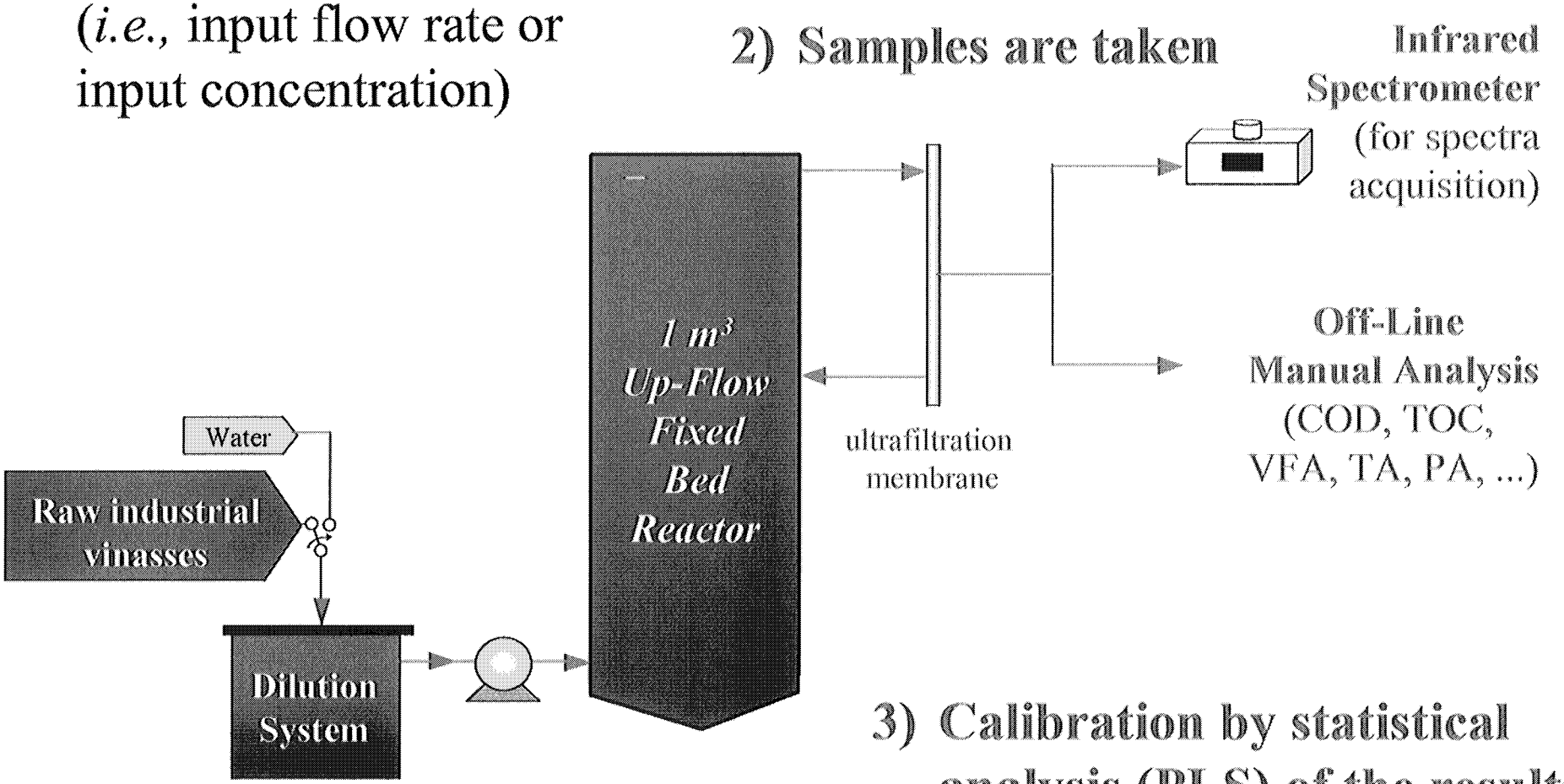


Spectra of Complex Samples



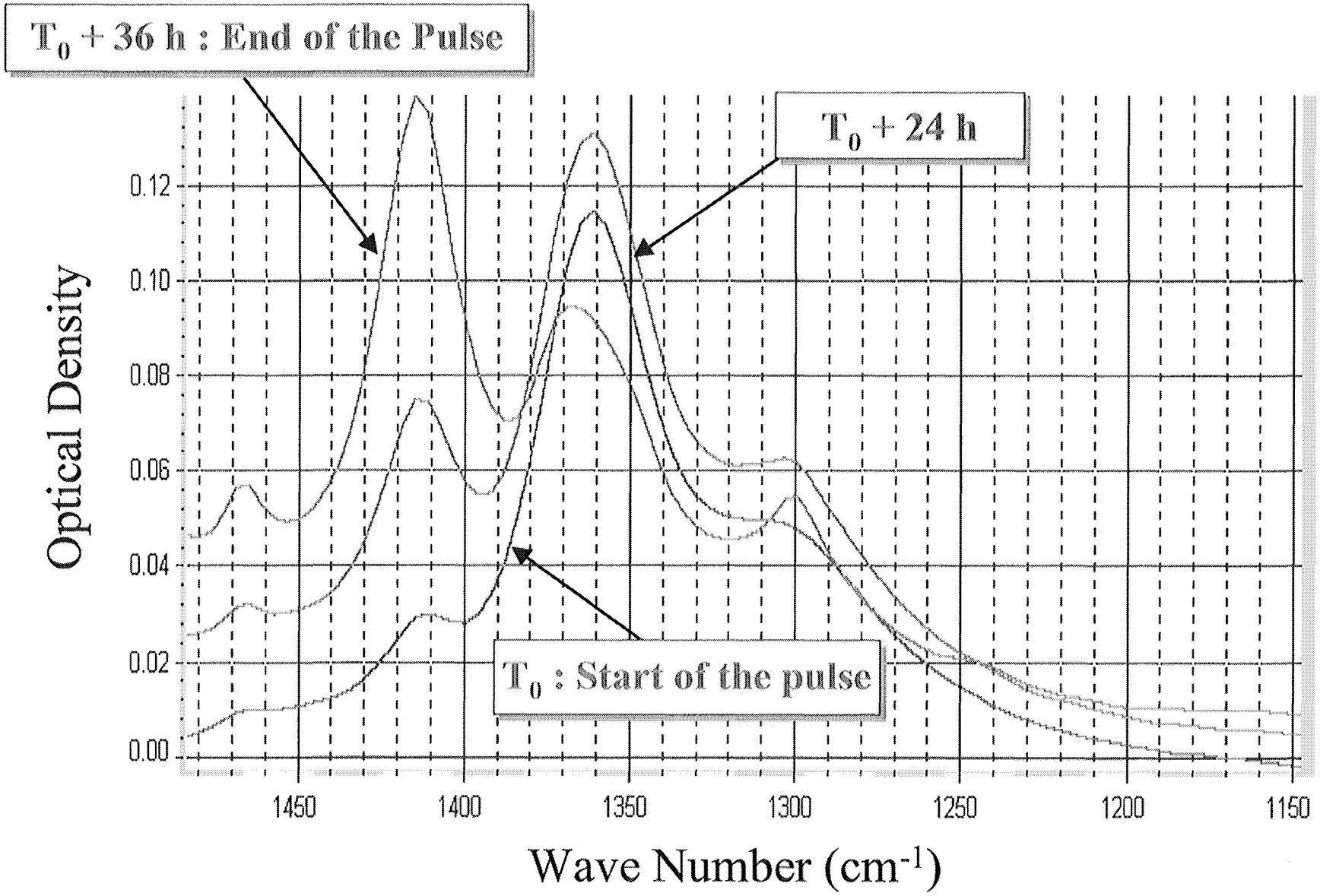
Calibration Principle

1) **Change of the organic loading rate** (*i.e.*, input flow rate or input concentration)



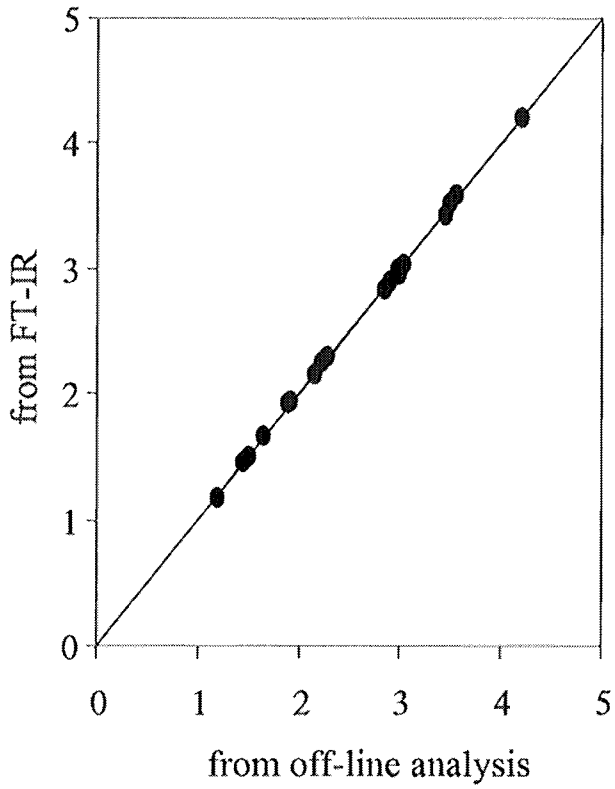
3) **Calibration by statistical analysis (PLS) of the results**

Spectra Evolution during a Pulse

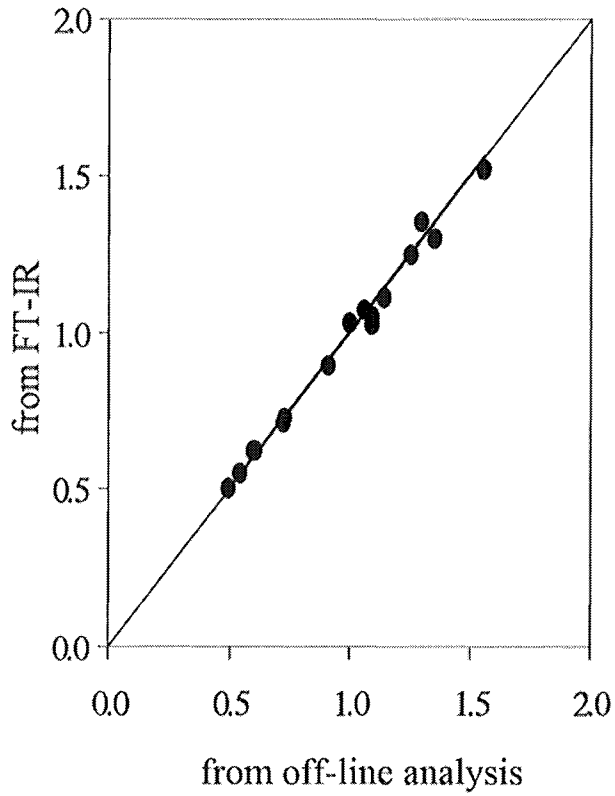


Calibration Results

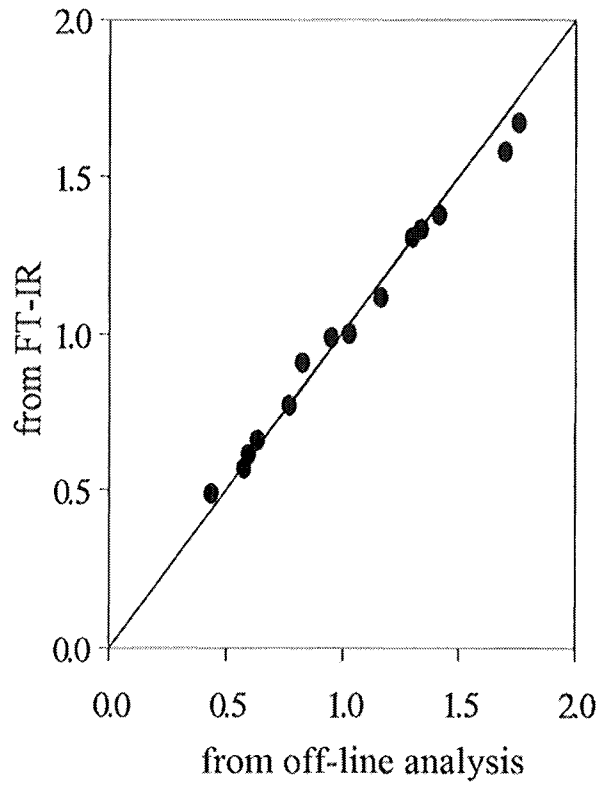
CODs (g/l)



TOC (g/l)



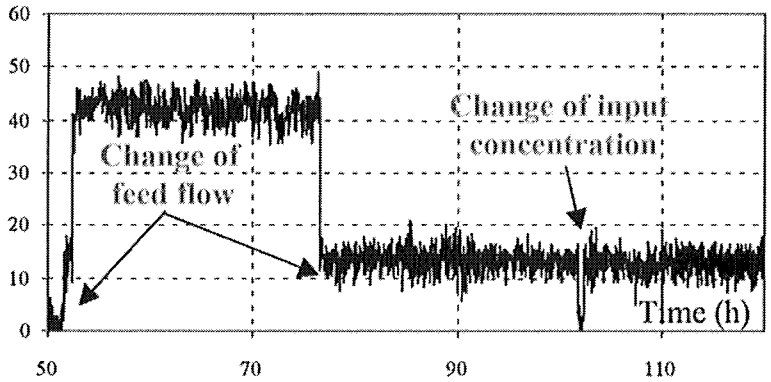
VFA (g/l)



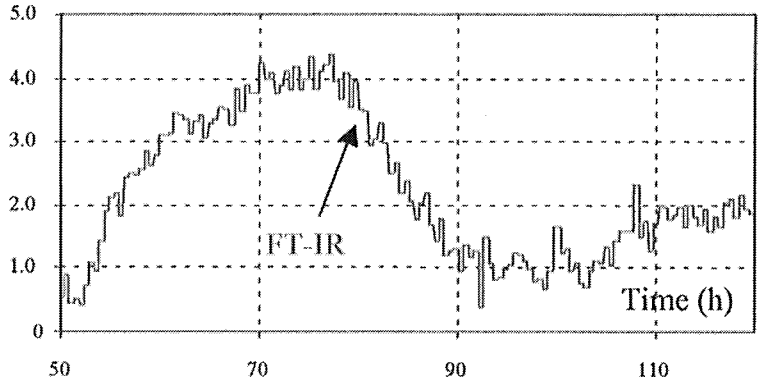
Similar results on partial and total alkalinity

On-Line Results

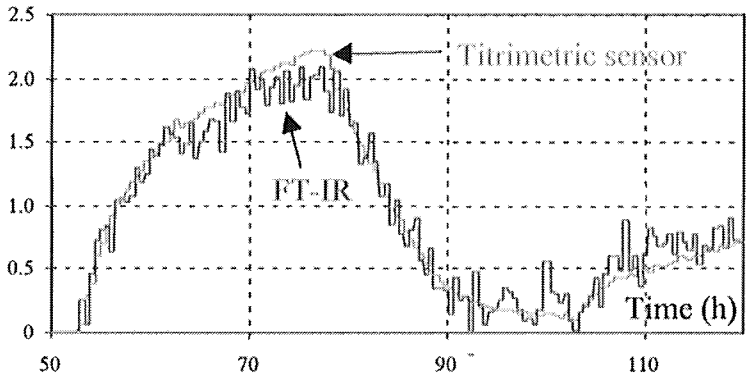
Influent flow rate (l/h)



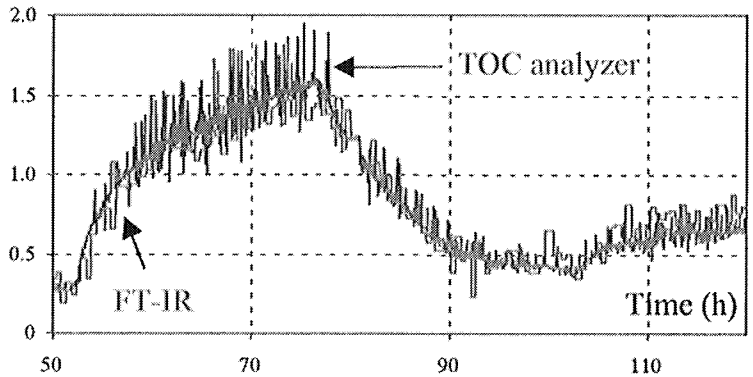
Soluble Chemical Oxygen Demand (g/l)



Volatile Fatty Acids (g/l)

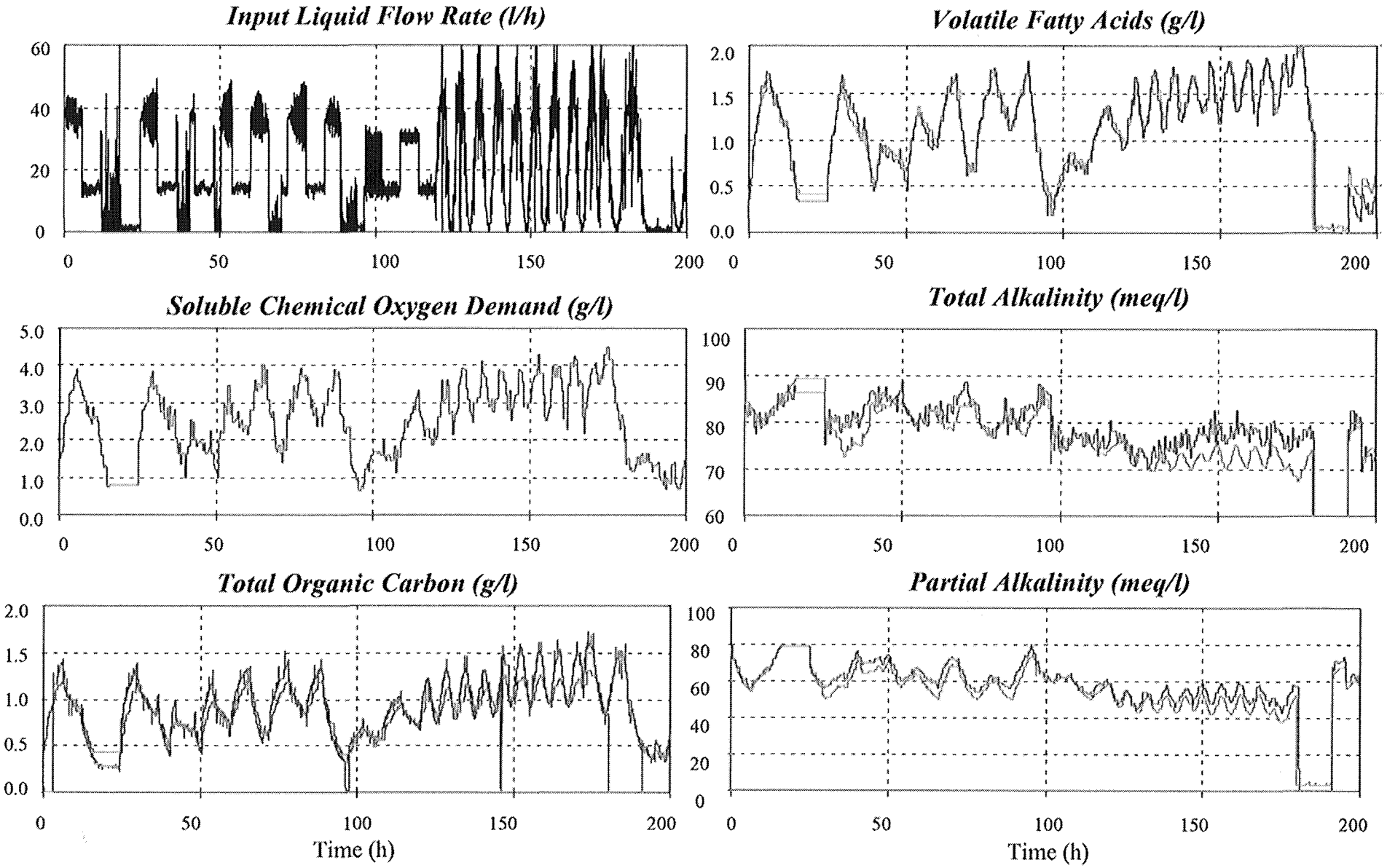


Total Organic Carbon (g/l)



Similar results on partial and total alkalinity

One Year Later (i.e., after many changes of vinasses)



Contents of the Presentation

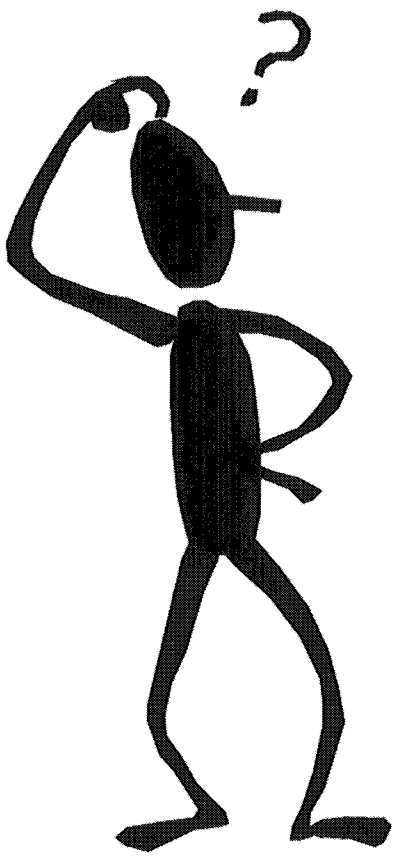
1) The anaerobic digestion process

2) Some examples of (off-line) sensors

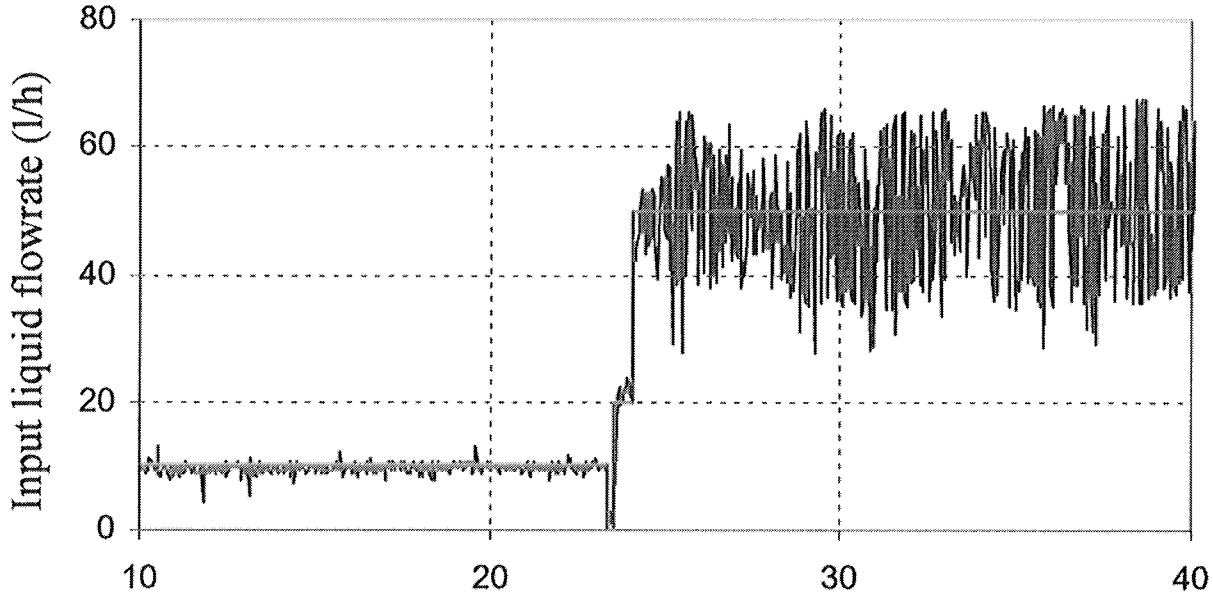
3) Practical illustration of on-line sensors

4) Benefits from on-line instrumentation

Benefits from fully instrumented process

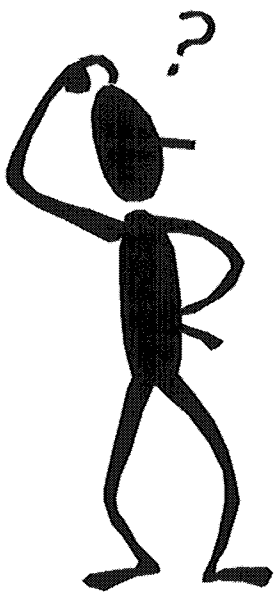


What happens if the organic loading rate changes ?

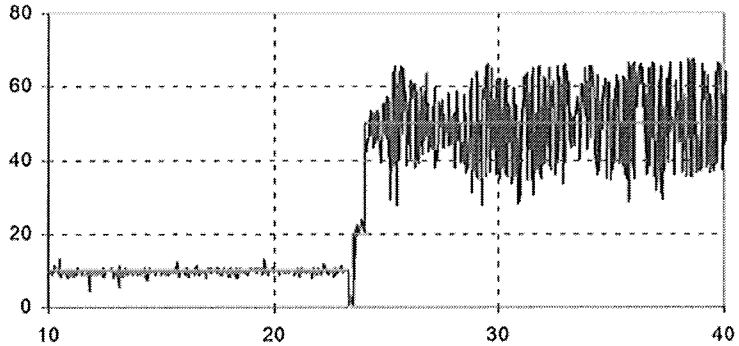


Benefits from fully instrumented process

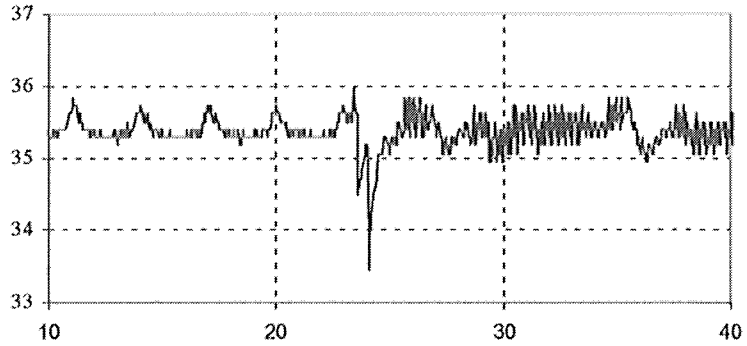
From the classical measurements in the liquid phase



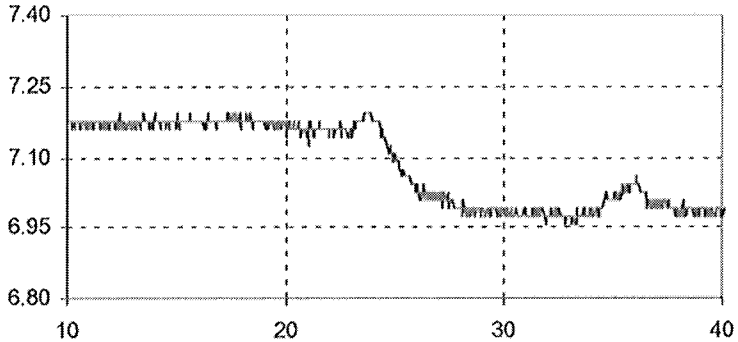
Input liquid flowrate (l/h)



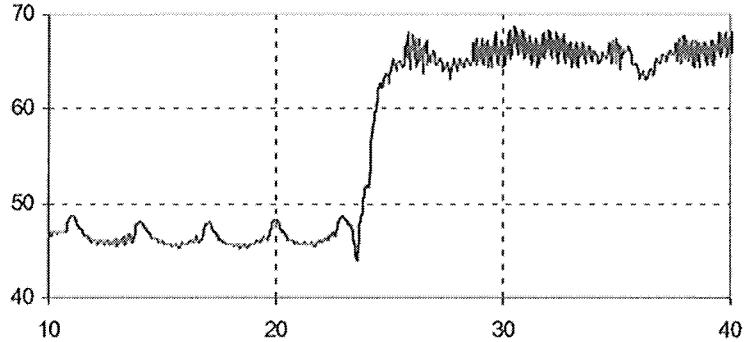
Temperature of the reactor (°C)



pH (UpH)

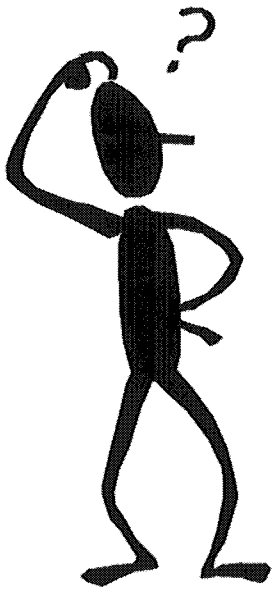


Temperature of the heater (°C)

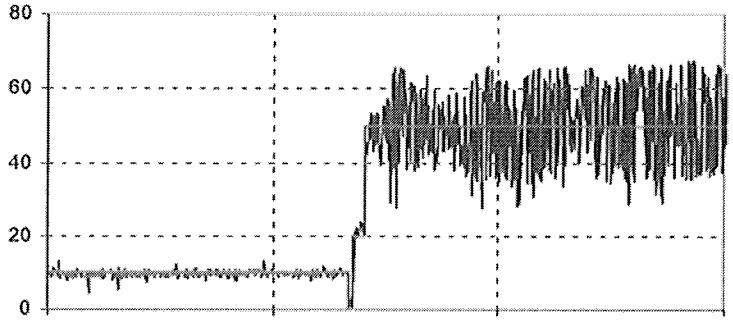


Benefits from fully instrumented process

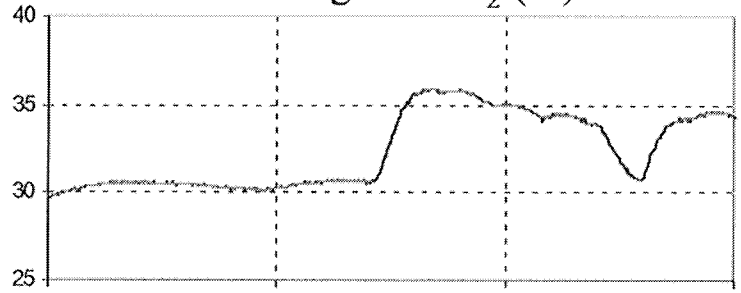
From the more or less classical measurements in the gas phase



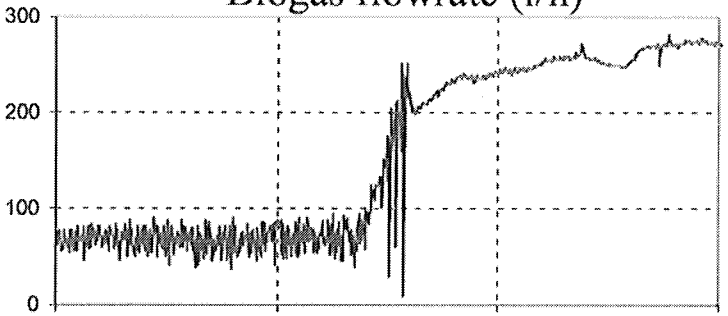
Input liquid flowrate (l/h)



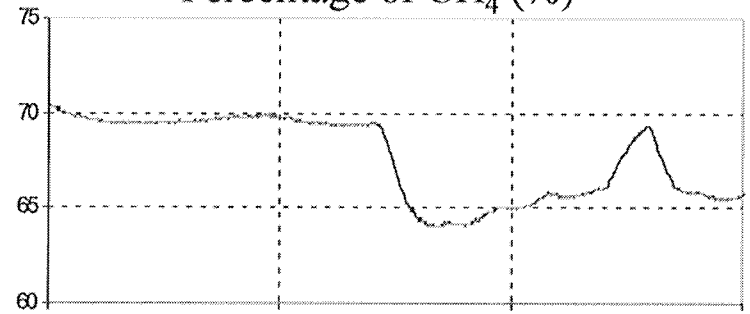
Percentage of CO_2 (%)



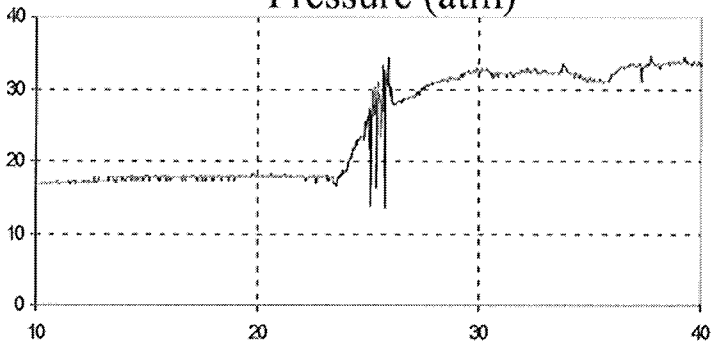
Biogas flowrate (l/h)



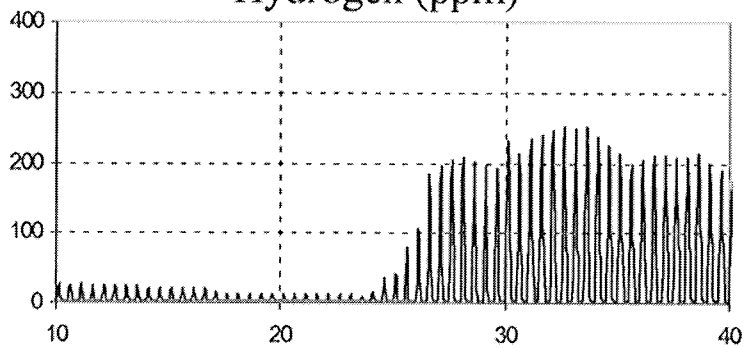
Percentage of CH_4 (%)



Pressure (atm)

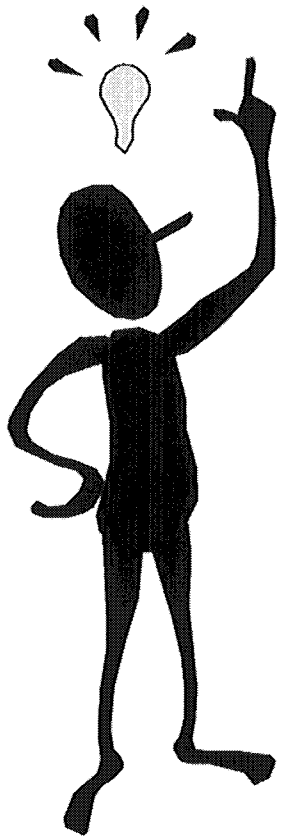


Hydrogen (ppm)

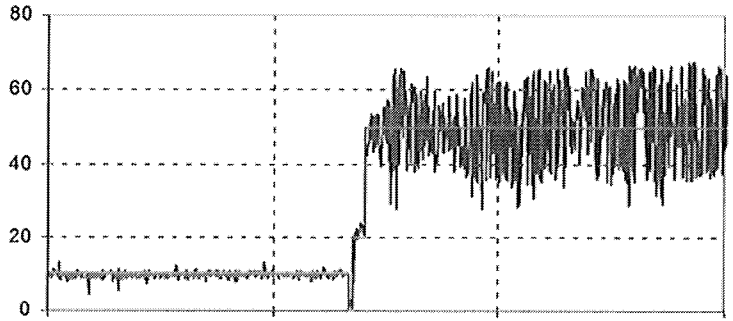


Benefits from fully instrumented process

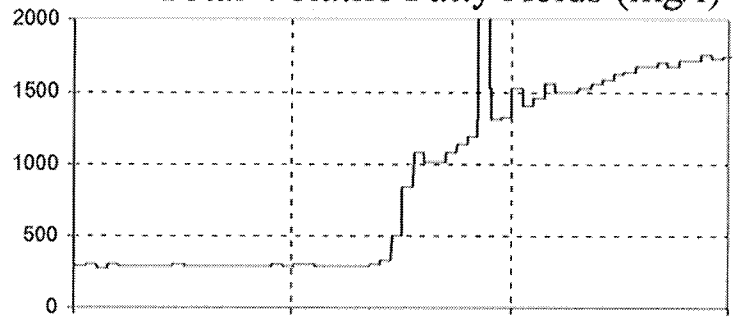
From the non classical measurements in the liquid phase



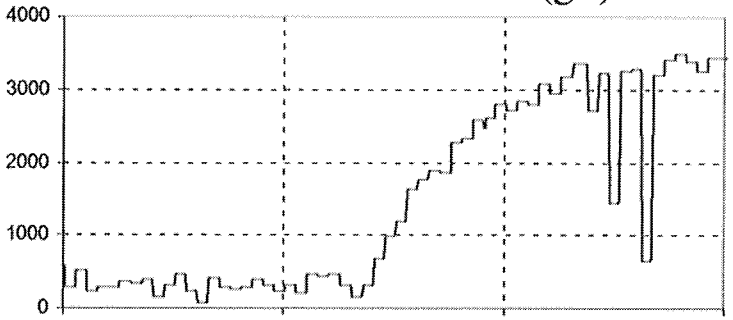
Input liquid flowrate (l/h)



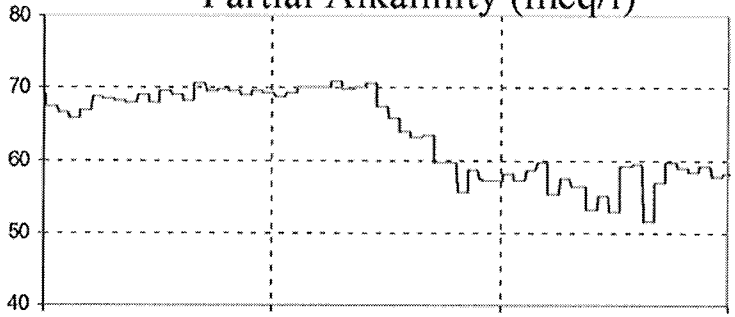
Total Volatile Fatty Acids (mg/l)



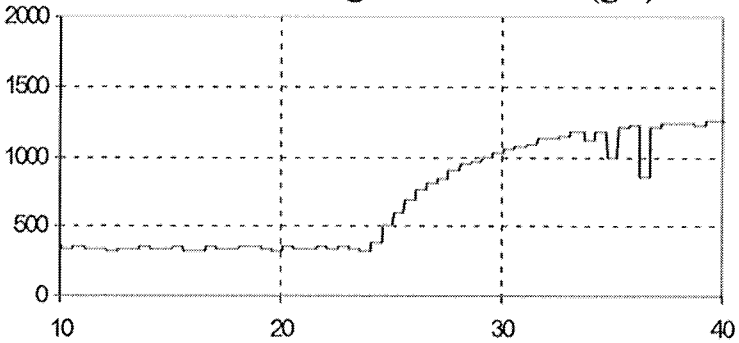
Soluble COD (g/l)



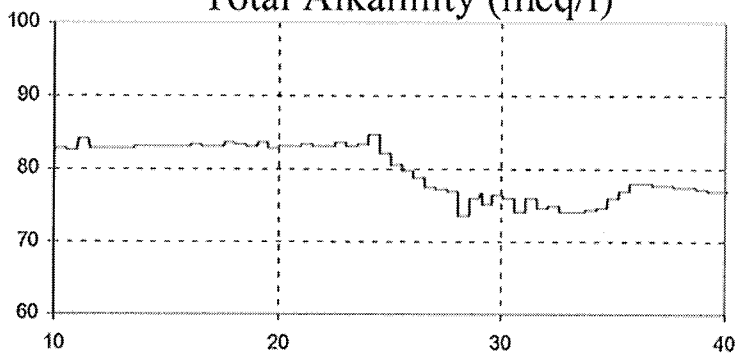
Partial Alkalinity (meq/l)



Total Organic Carbon (g/l)

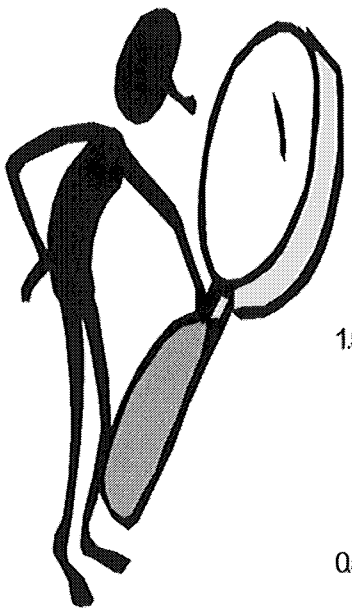


Total Alkalinity (meq/l)

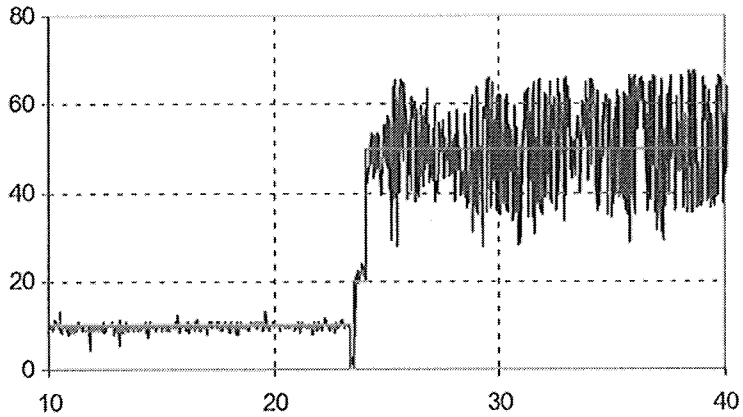


Benefits from fully instrumented process

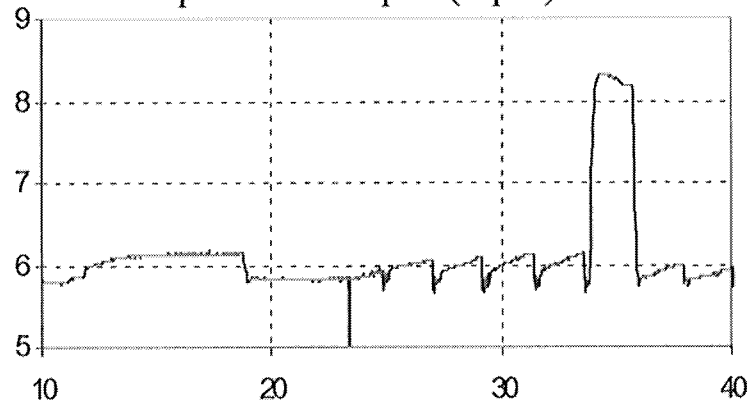
We can even get closer !...



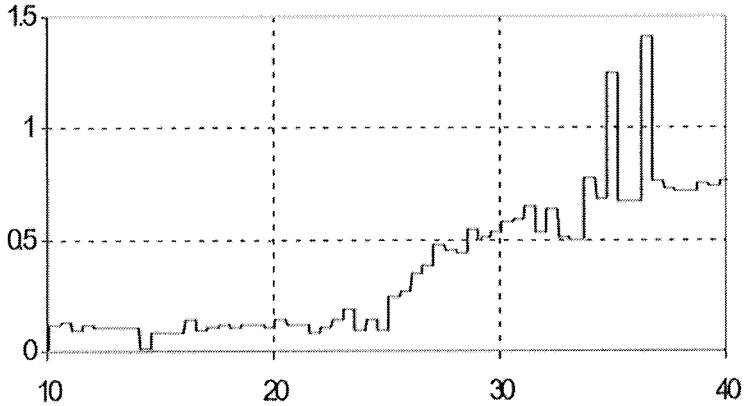
Input liquid flowrate (l/h)



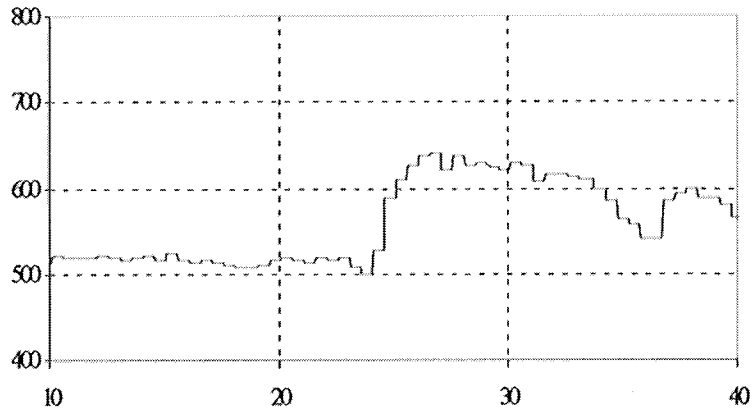
pH in the input (UpH)



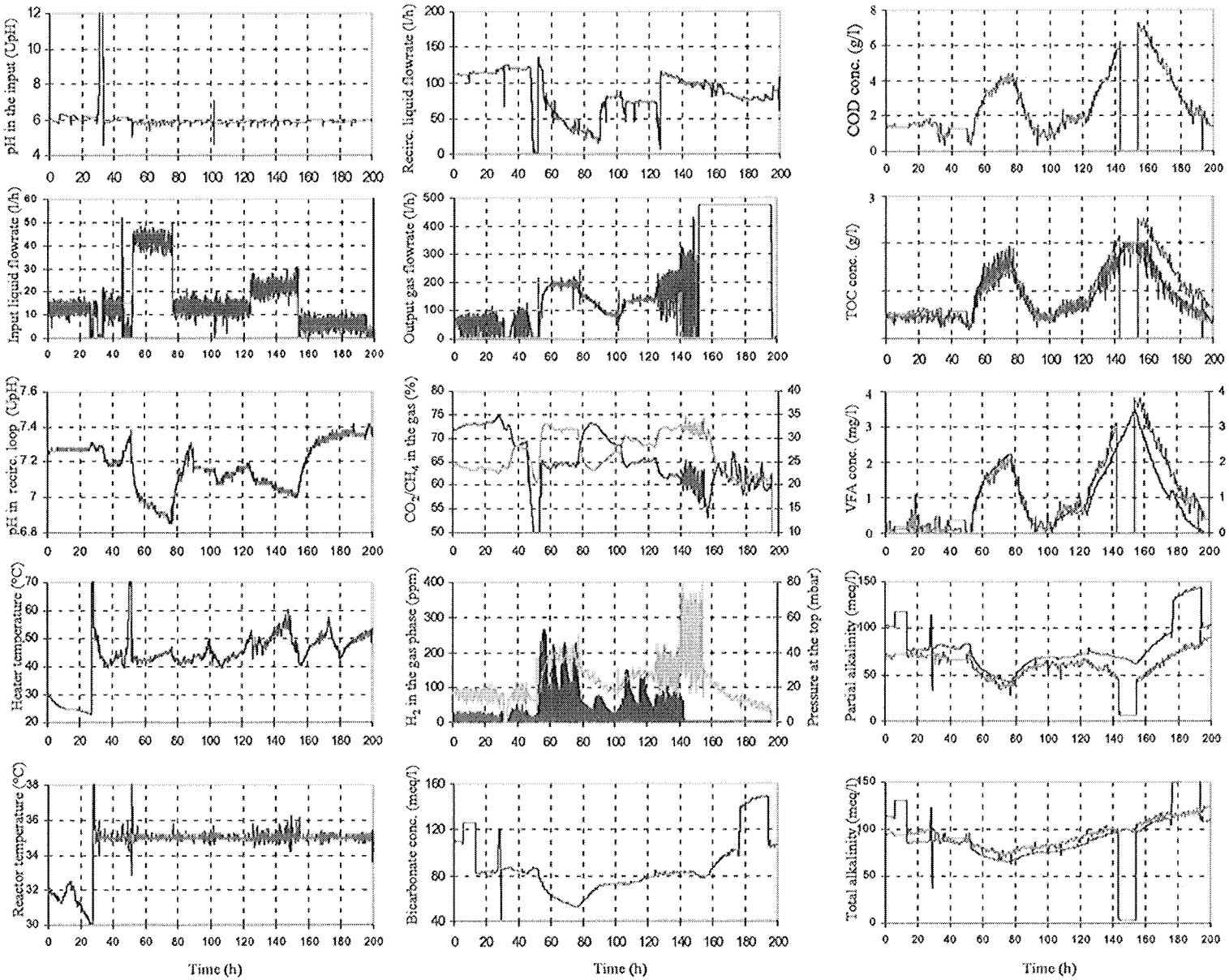
Specific Volatile Fatty Acids (g/l)



Dissolved CO_2



Benefits from fully instrumented process



Benefits from fully instrumented process

Advantages :

☺ Dynamic (vs. static) and global view of the process

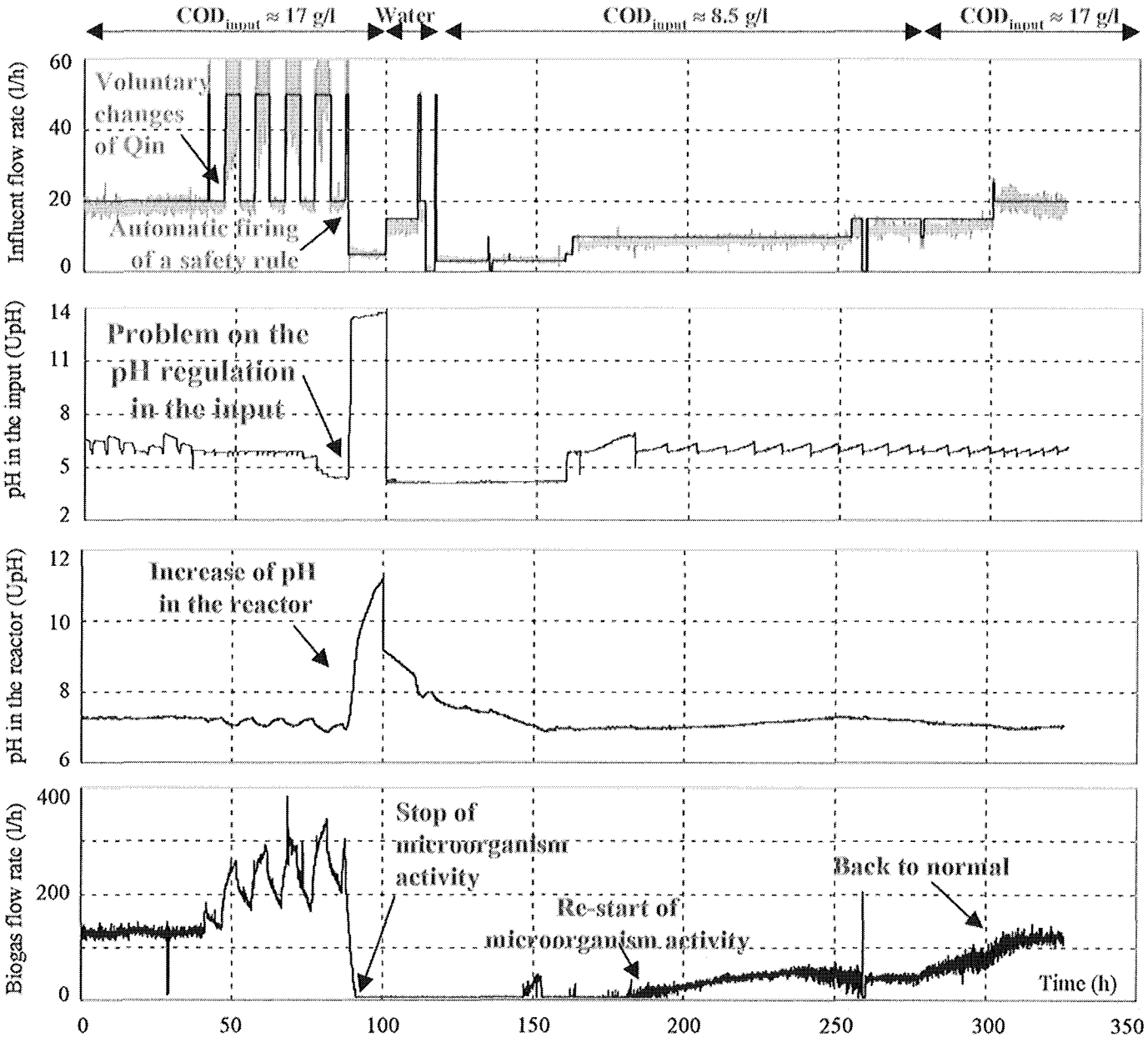
☺ Deep understanding of the phenomena

☺ Door open to optimal management of WWTPs

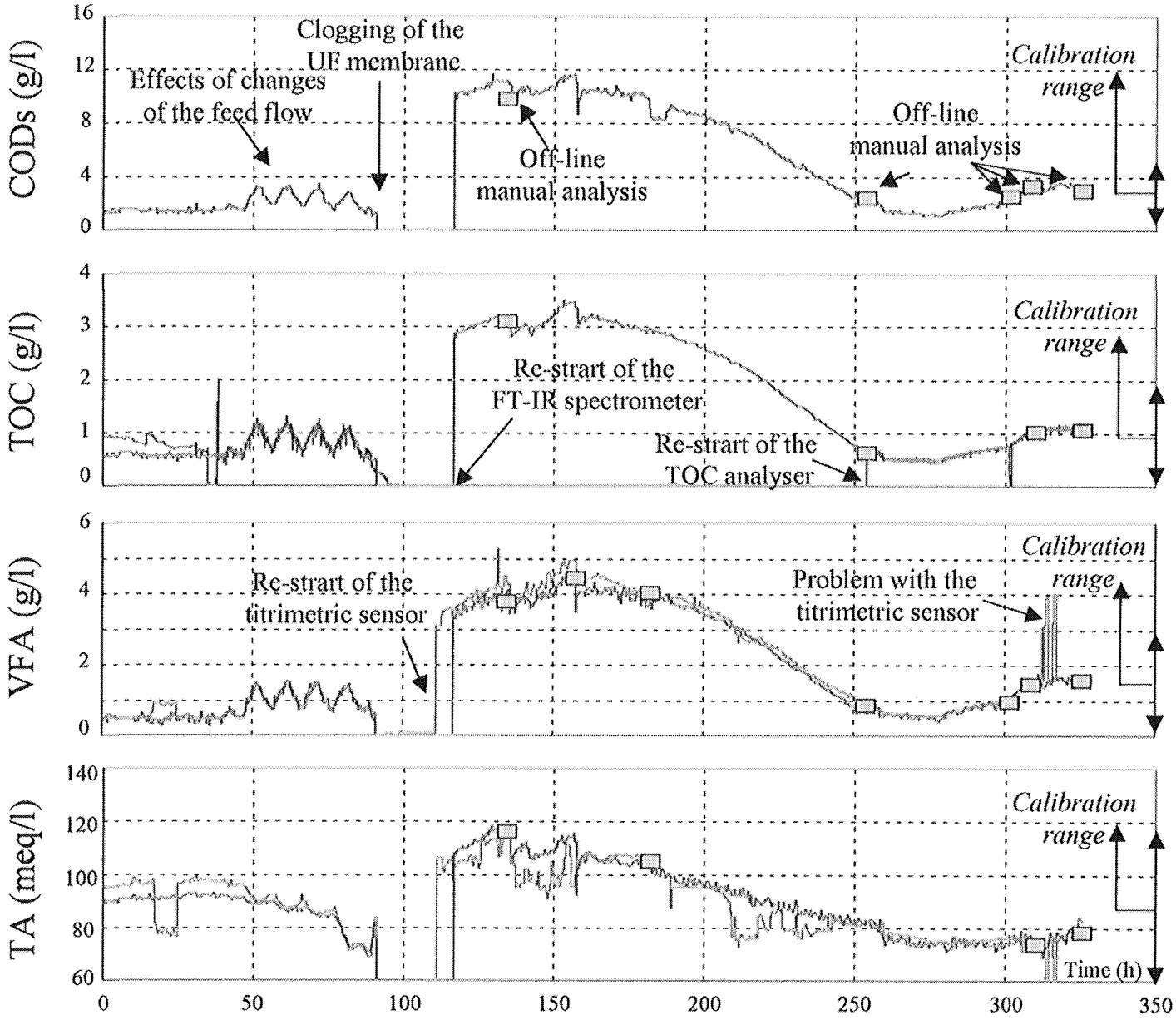
Drawbacks :

☹ Expensive (money *and* maintenance)

Application (1) : Monitoring of AD processes

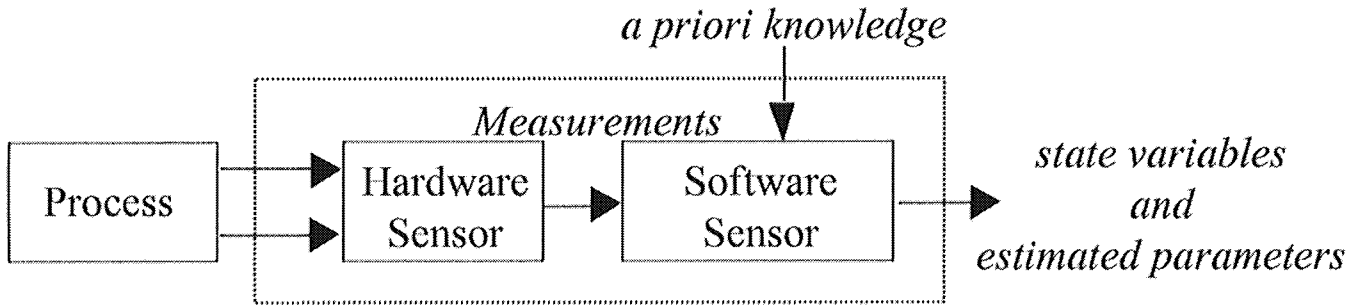


Application (1) : Monitoring of AD processes

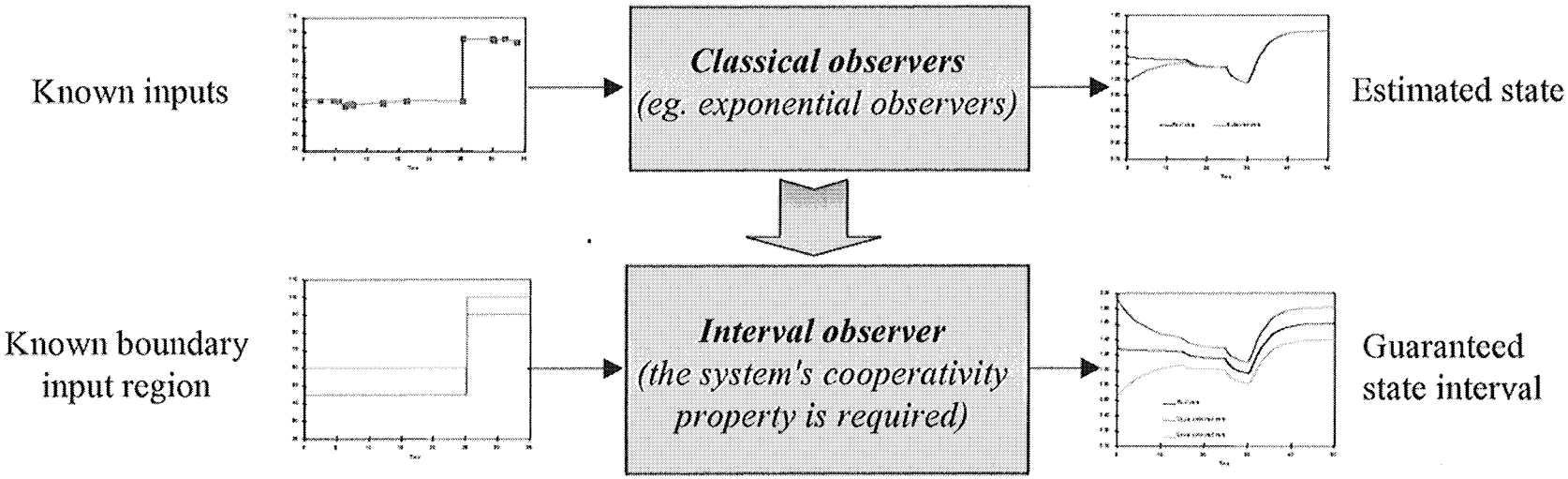


Application (2) : Software sensors

When technical solutions are not available, it can be useful to combine sensor signals within a mathematical framework in order to estimate unknown parameters.



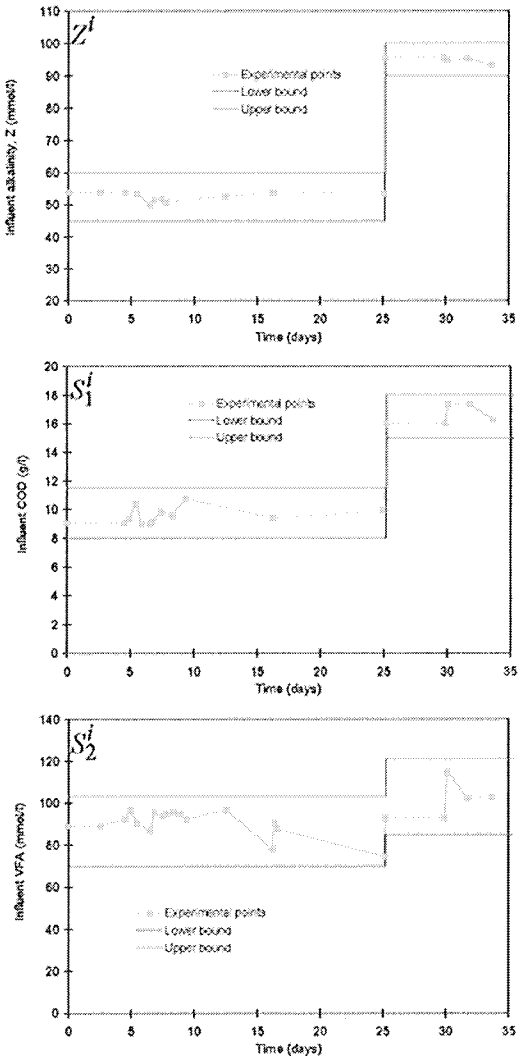
Software sensors in WWTPs : Internal observers



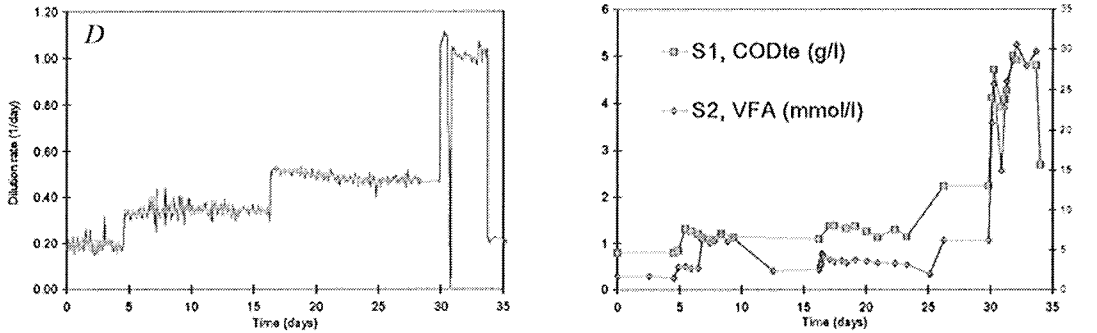
If the observer is cooperative, the estimated state are guaranteed to live within the estimated bounds

Application (2) : Software sensors

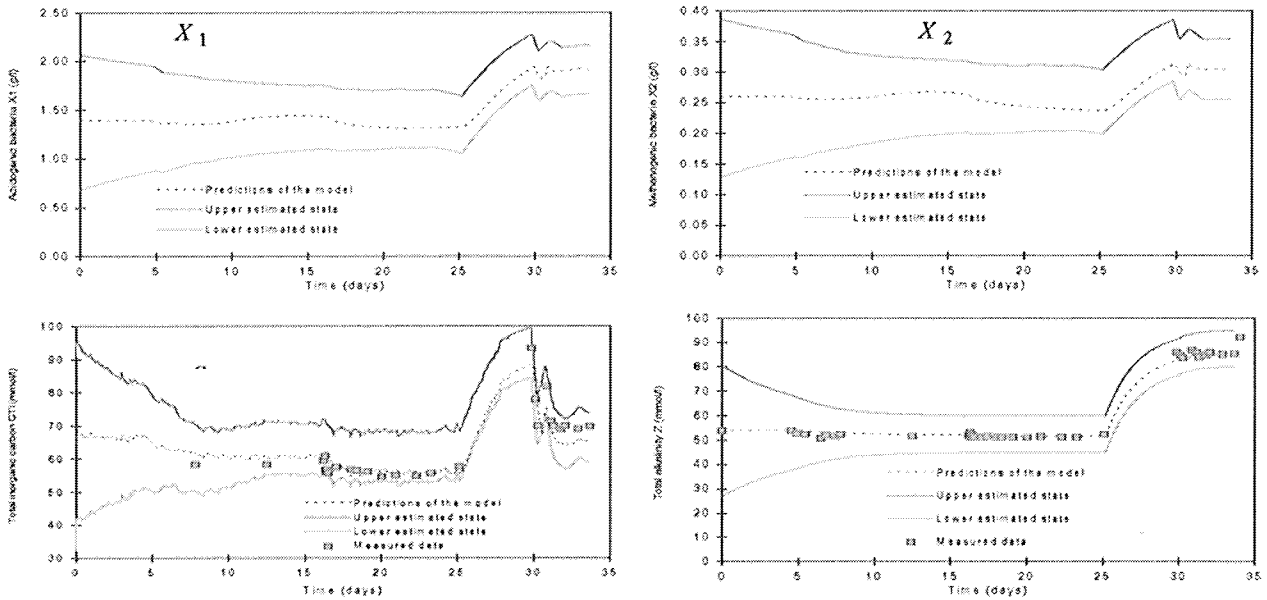
Hypothesis about the inputs of the process (knowledge of the bounds)



On-line measurements on the process

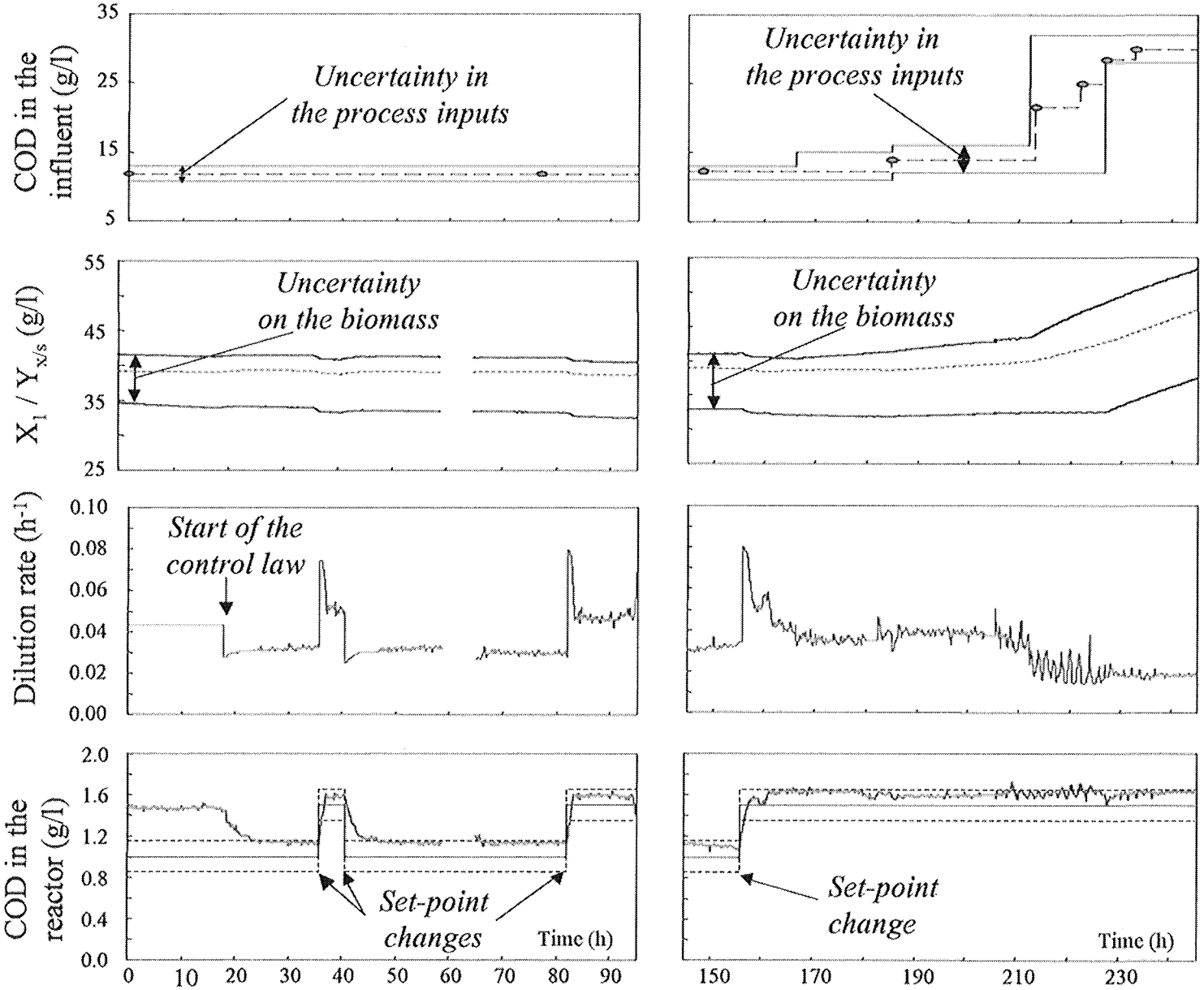


Estimations of the intervals : Comparison with experimental off-line data



Application (3) : Advanced Control of AD processes

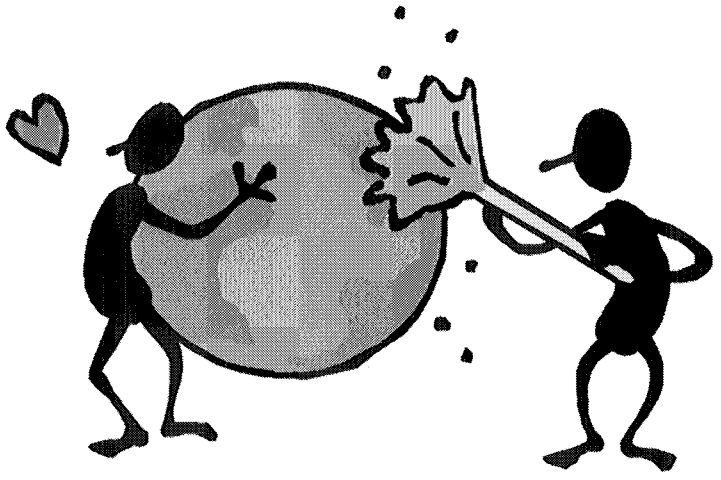
Robust Interval Based Regulation of COD in the reactor



Conclusion

- *On-line instrumentation is mandatory*
- *It allows large benefits*
- *Reliability is coming*
- *In the near future : spectral measurements*
- *In the long future : molecular tools*

Thank you very much for your attention !



I will be very happy to answer your questions