DIPARTIMENTO DI SISTEMI E INFORMATICA
FACOLTA' DI INGEGNERIA
VIA S. MARTA, 3
50139 FIRENZE

Prof. Stefano Marsili-Libelli
Tel e fax: (055) 47.96.264
Email: marsili@ingfi1.ing.unifi.it

AVVISO DI SEMINARIO

Giovedì 25 Novembre p.v. alle ore 9:00
nell'Aula Seminari del Dipartimento di Energetica "Sergio Stecco" (g.c.)
primo piano, lato Est.

Il Prof. Peter Vanrolleghem

On-line characterization of waste load and toxicity with activated sludge respirometry

Abstract

Respirometry, the measurement of the oxygen consumption by organisms for substrate degradation and cell maintenance, has become one of the key monitoring techniques in wastewater treatment.

After some introduction on the different respirometric measuring principles, focus of the presentation will be put on the on-line application of batch-wise operating respirometers on full-scale plants. They allow to characterize the waste load (BODst and substrate fractions, including nitrifiable nitrogen) and potential toxicity of influents.

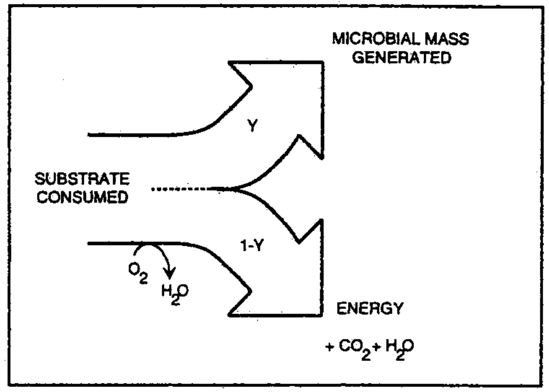
The usefulness and current implementation in wastewater treatment plant control will be discussed.

IAWQ Scientific and Technical Report (STR)

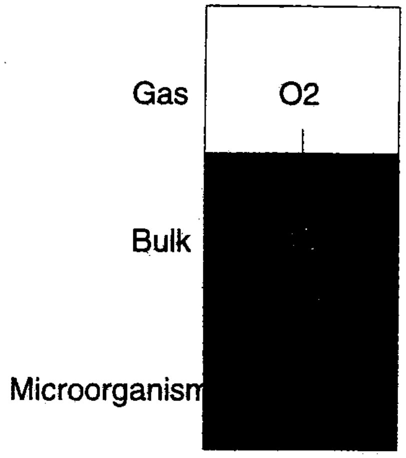
Respirometry in Control of the Activated Sludge Process

Henri Spanjers
Peter Vanrolleghem
Gustaf Olsson
Peter Dold

Substrate consumption

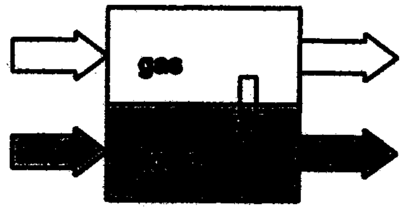


Respirometers



- Respiration takes place in liquid
- Uptake of DO from liquid
- Transfer of O_2 from gas to liquid
- Dynamic oxygen mass balans

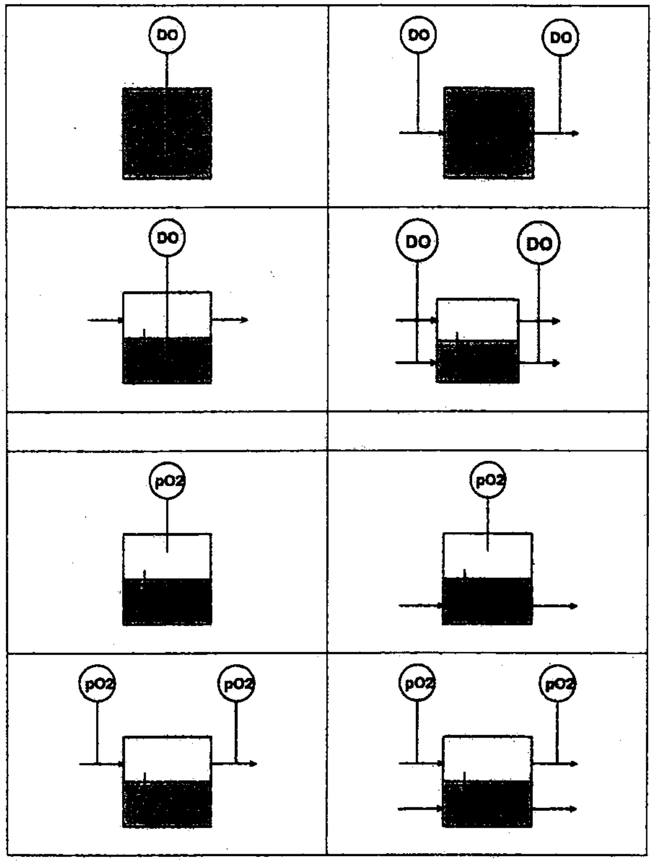
Generic Respirometer



Phase of Oxygen measurement: Gas or Liquid

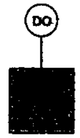
Flow regime: Static or Flowing

Eight different principles



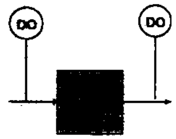
Liquid phase principles

LSS no gas flow, no liquid flow



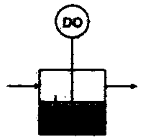
$$\frac{dC_L}{dt} = -r$$

LSF no gas flow, with liquid flow



$$\frac{dC_L}{dt} = \frac{Q}{V_L}(C_{L,in} - C_L) - r$$

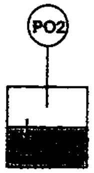
LFS with gas flow, no liquid flow



$$\frac{dC_L}{dt} = K_L a(C_L^* - C_L) - r$$

Gas phase principles

GSS no gas flow, no liquid flow;
constant V



$$\frac{dC_L}{dt} = K_La(C_L^* - C_L) - r$$

$$\frac{dC_G}{dt} = -\frac{V_L}{V_G}K_La(C_L^* - C_L)$$

WQI '96, Singapore, 23-28 June Principles 9

Summary Respirometric Principles

respirometric principle → process ↓		LSS	LSF	LFS	LFF	GSS	GSF	GFS	GFF
		liquid phase				gas phase			
respiration	r	-1	-1	-1	-1	-1	-1	-1	-1
dissolved oxygen accumulation	$\frac{dC_L}{dt}$	-1	-1	-1	-1	-1	-1	-1	-1
liquid volume change	$\frac{C_L}{V_L}\frac{dV_L}{dt}$		-1		-1		-1		-1
liquid flow	$\frac{Q_{in}}{V_L}C_{L,in} - \frac{Q_{out}}{V_L}C_L$		1		1		1		1
gas exchange	$K_La(C_L^* - C_L)$			1	1	1	1	1	1
gaseous oxygen accumulation	$\frac{dC_G}{dt}$					-1	-1	-1	-1
gas volume change	$\frac{C_G}{V_G}\frac{dV_G}{dt}$					-1	-1	-1	-1
gas flow	$\frac{F_{in}}{V_G}C_{G,in} - \frac{F_{out}}{V_G}C_G$							1	1
gas exchange	$\frac{V_L}{V_G}K_La(C_L^* - C_L)$					-1	-1	-1	-1

Introduction

OXYGEN:

a Key Variable in Wastewater Treatment

(1) - COD Removal / - Nitrification => Effluent Quality

(2) - Aeration Cost => Economy

MICROBIAL RESPIRATION RATE

a Look at the Interaction between
- Wastewater
- Biocatalysts

providing Insight in:

- Composition
- Biodegradability
- Degradation Rate
- Adaptation Time
- Toxicity (Acute & Chronic)

- Sludge Viability/Activity (Actual/Potential)

On-line Influent Composition Assessment

WHY ?

Knowledge on Future Load Variations
Knowledge on Future Potential Toxicity

=> Feedforward Control

WHERE ?

As far Upstream of the Works as possible and still Provide Relevant Information

HOW ?

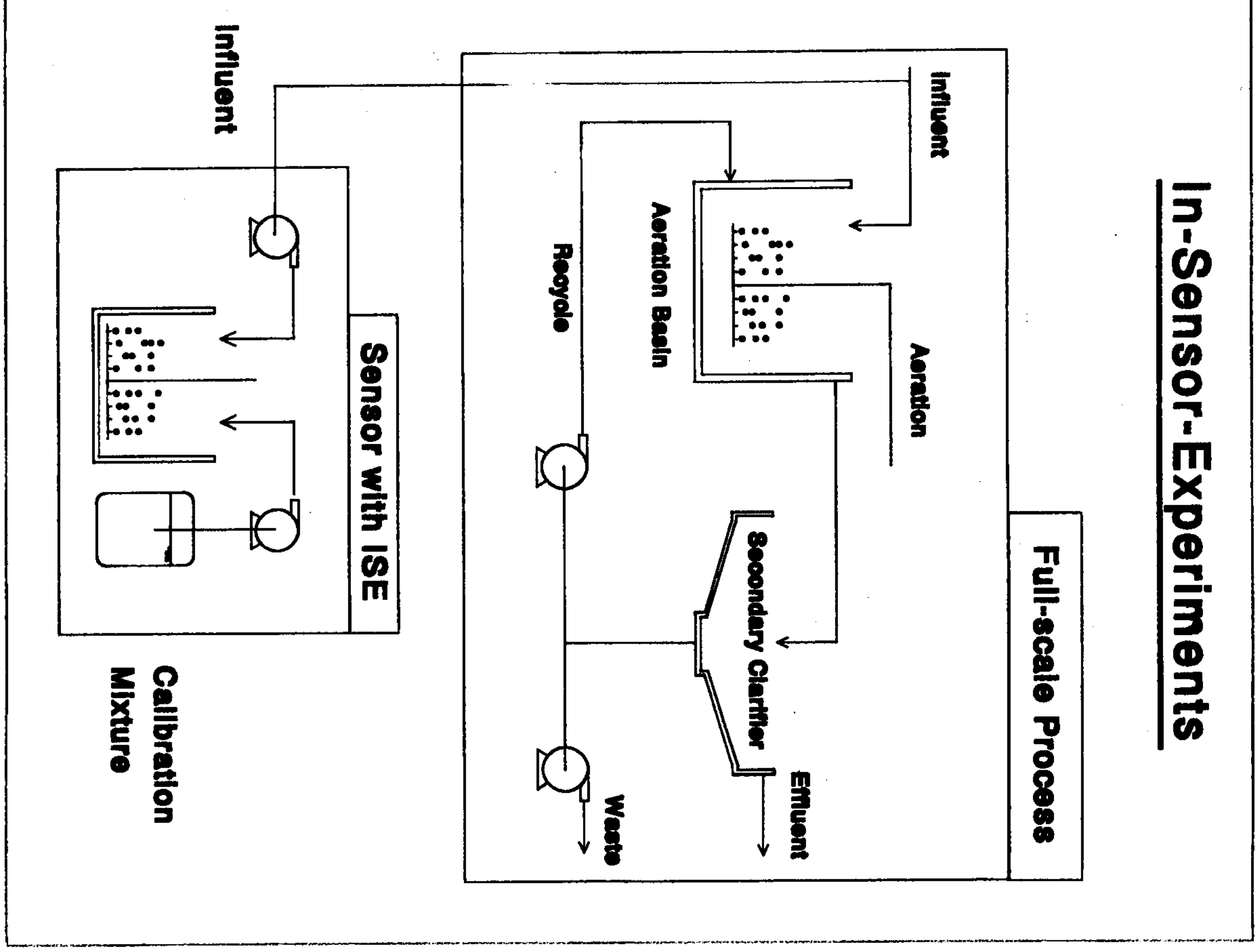
Chemical: TOC, COD, TOD
Physical: Conductivity, UV-absorption

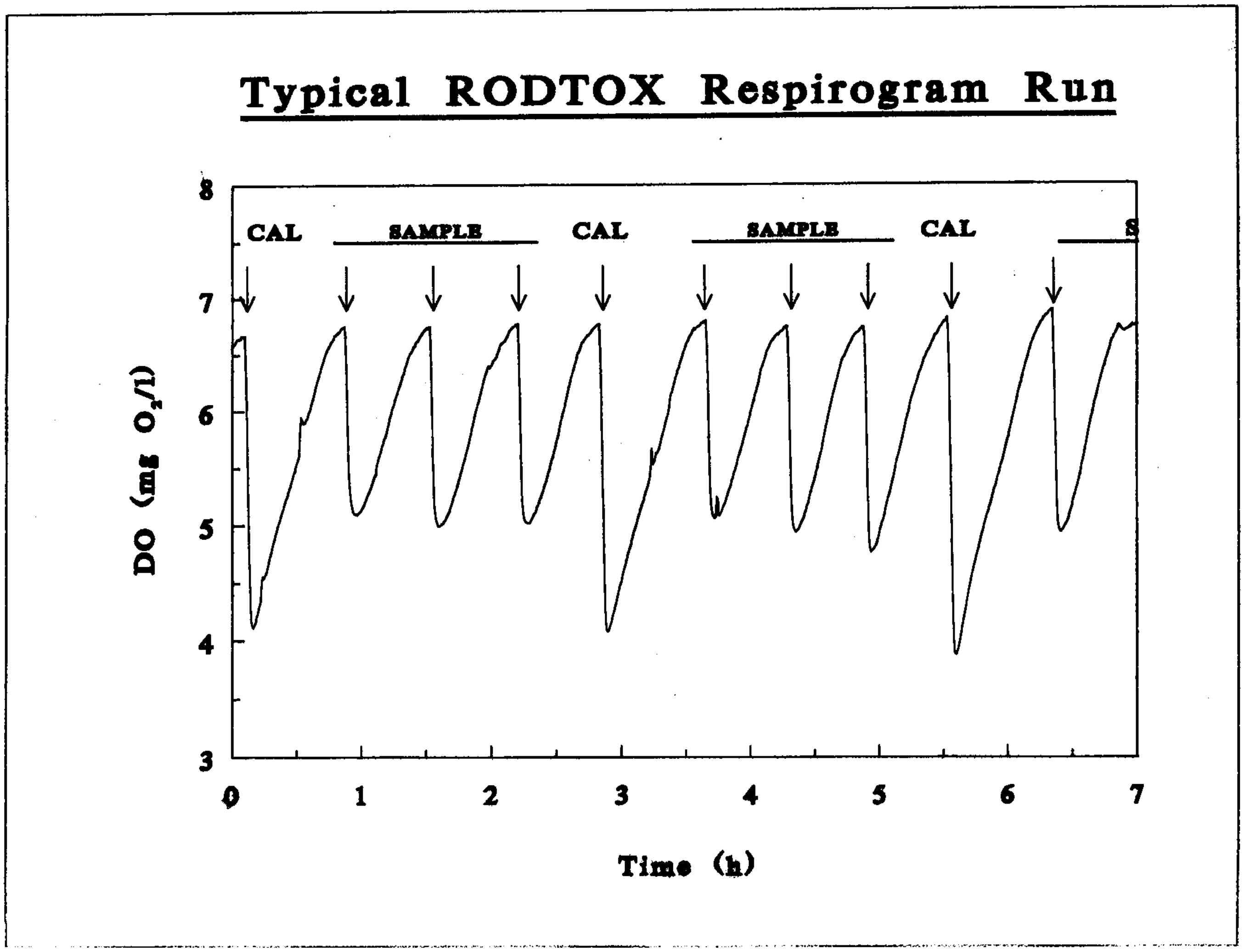
Advantages:	Fast Standardized
Disadvantages:	Maintenance Biodegradability Toxicity

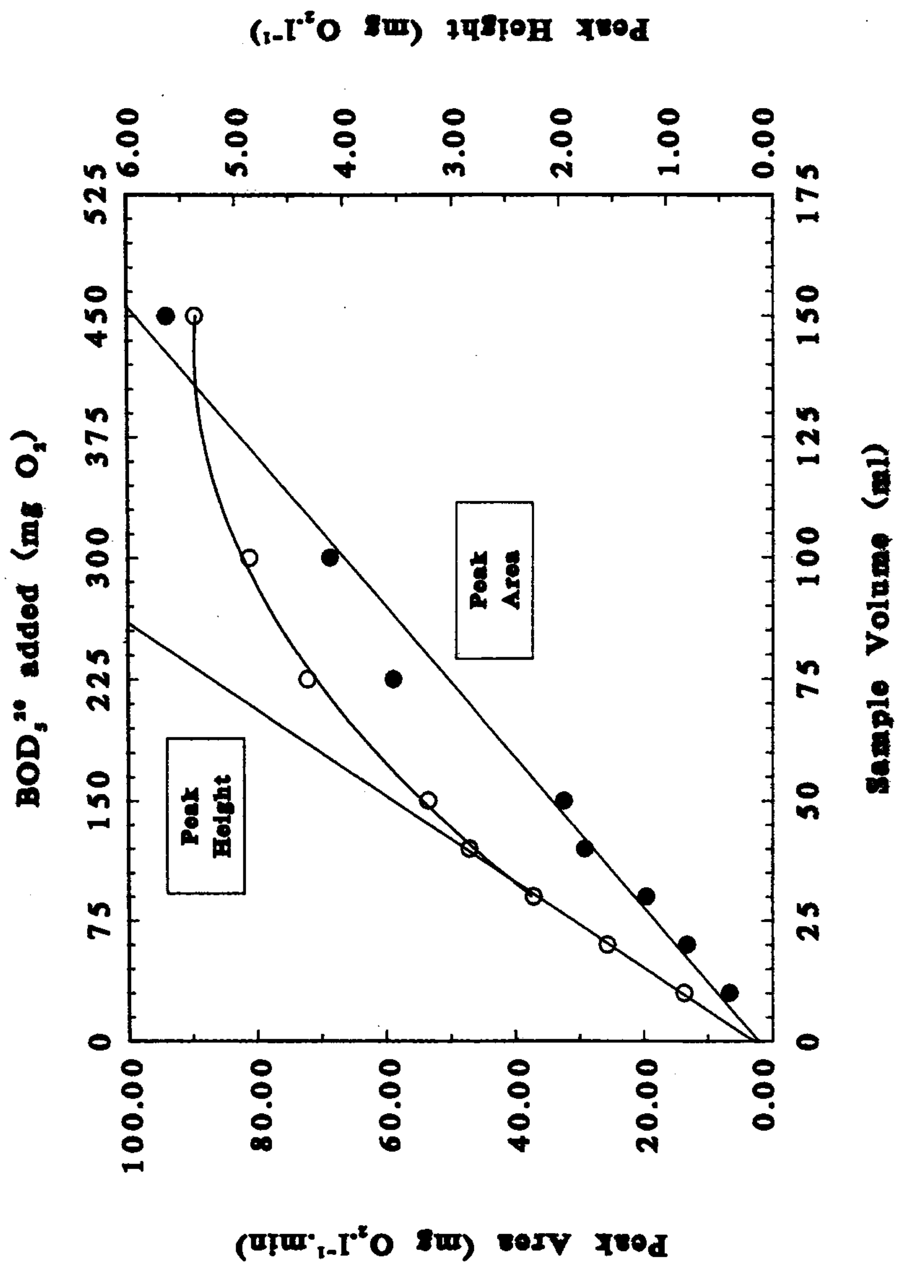
Biological: BOD_5^{20}

Advantages:	Biodegradability Toxicity
Disadvantage:	Slow

=> BOD_{st}


In-Sensor-Experiments
Full-scale Process
Influent
Aeration
Aeration Basin
Recycle
Secondary Clarifier
Effluent
Waste
Sensor with ISE
Influent
Calibration Mixture


Typical RODTOX Respirogram Run
CAL
SAMPLE
CAL
SAMPLE
CAL
DO (mg O2/l)
Time (h)
0
1
2
3
4
5
6
7
3
4
5
6
7
8



BOD_{st} Calculation

General

$$BOD_{st} = \int_0^{tfin} OURex(t)\,dt$$

Using OURex(t) Profiles Generated with Both Principles
=> BOD_{st} Injected in the Vessel can be Calculated

$$BOD_{st}(sample) = \frac{Vsample}{Vvessel} BOD_{st}(vessel)$$

Special Case One-Vessel Principle

BOD_{st} can be calculated readily from DO-data

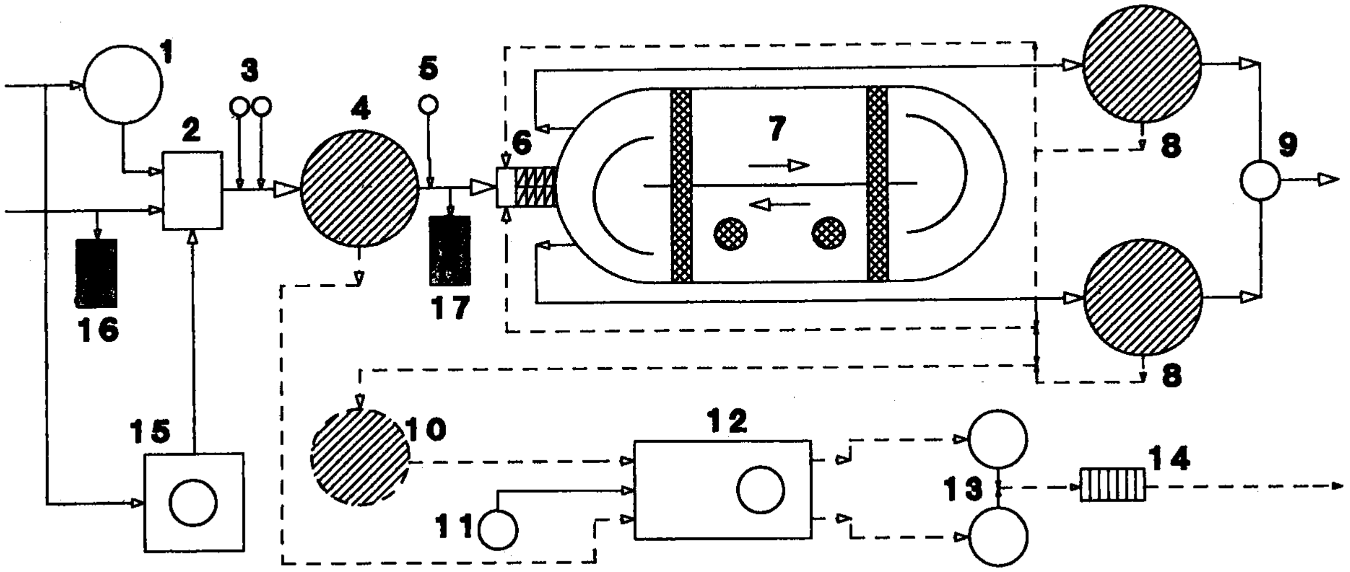
$$\int_0^{tfin} dC = \int_0^{tfin} K_La\,(Ce-C[t])\,dt - \int_0^{tfin} OURex[t]\,dt$$

$$\underbrace{C(tfin) - C(0)}_{=0} = \int_0^{tfin} K_La\,(Ce-C[t])\,dt - \underbrace{\int_0^{tfin} OURex[t]\,dt}_{=BODst}$$

$$BOD_{st} = K_La\,A$$

With this, one can eliminate K_La:

$$BOD_{st}^{X} = \frac{K_La\,A^{X}}{K_La\,A^{Cal}} BOD_{st}^{Cal}$$



1. COD Buffer Tank
2. Equalization Basin
3. pH Control Equipment
4. Primary Clarifier
5. P-dosing Unit
6. Archimedes Screws
7. Aeration Basin
8. Secondary Clarifier
9. Effluent Tank
10. Sludge Thickener
11. $FeCl_3/CaCO_3$ dosing Unit
12. Sludge Conditioning
13. Sludge Buffer Tank
14. Sludge Filter Press
15. Calamity Basin
16. RODTOX 1
17. RODTOX 2

Application 1

Degussa Antwerp Industrial WWTP

Treatment Plant Configuration

Two Wastewater Supply Routes:
- Highly Varying Composition
- Constant Composition -> Buffer Tank

Calamity Basin for Toxicity/Overload Protection

Respirometer Setup

'1991: First Respirometer at Inlet Oxidation Ditch

Large Load Variations
Corresponding with Batch Productions

Increased Use for Off-line Analysis
- Biodegradability Tests, Toxicity
- Production Divisions' Invoice

'1993: Second Respirometer
at Highly Varying Wastewater Stream

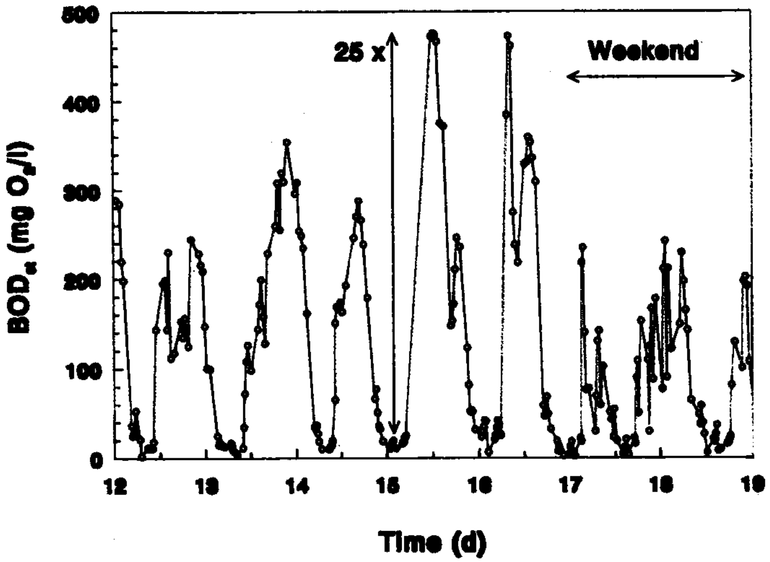
Feedforward Control Study

Control of Buffer Tank to - Equalize Loads
- Reduce Electricity Bill

Control of Calamity Basin to Protect for Overloads

Application 2
Maria Middelares Hospital WWTP

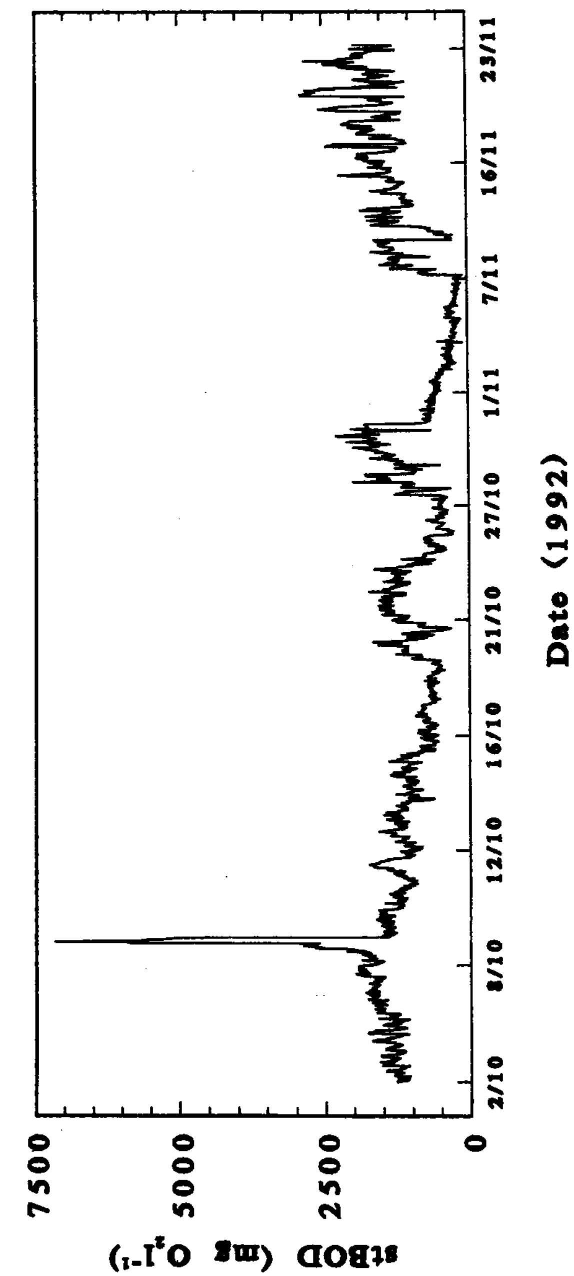
Experiment set up to Check Long-term Stability of Respirometric Devices for BOD_{st} (see below) and Toxicity Monitoring (Kong, in Preparation)



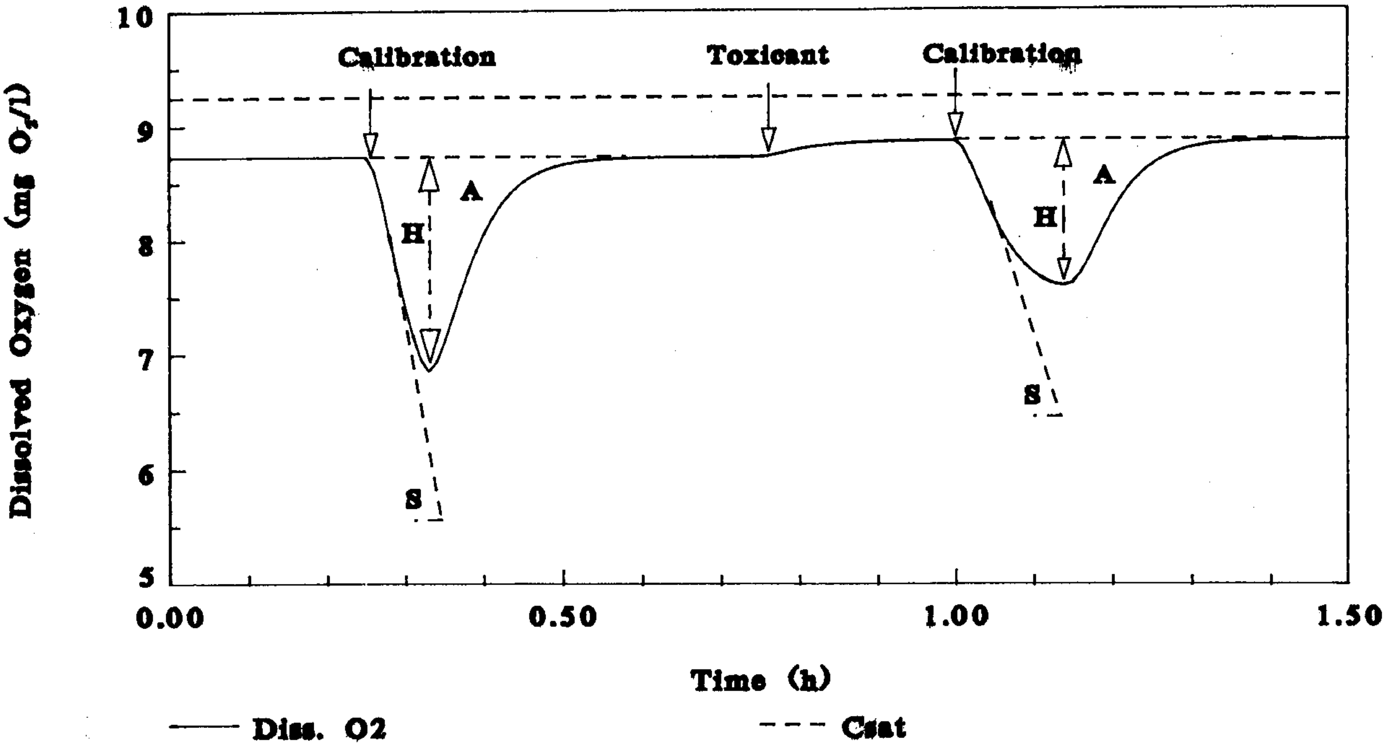
High Loads at Day-time when Staff is Present
Very Low Waste Content at Night
Reduced Pollutant Load during Weekends

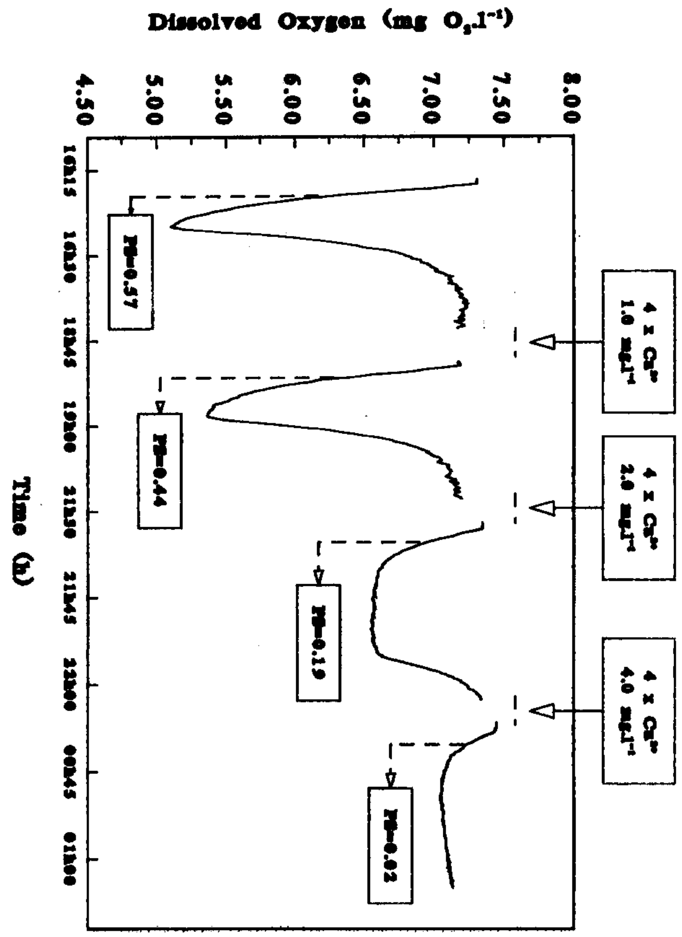
Implementations allow to Cover this BOD_{st} Range
With Buffer Tank, Load Equalization is Possible

RODTOX Wastewater Load Monitoring
2 months, 1800 respirograms



RODTOX TOXICITY Test PRINCIPLE





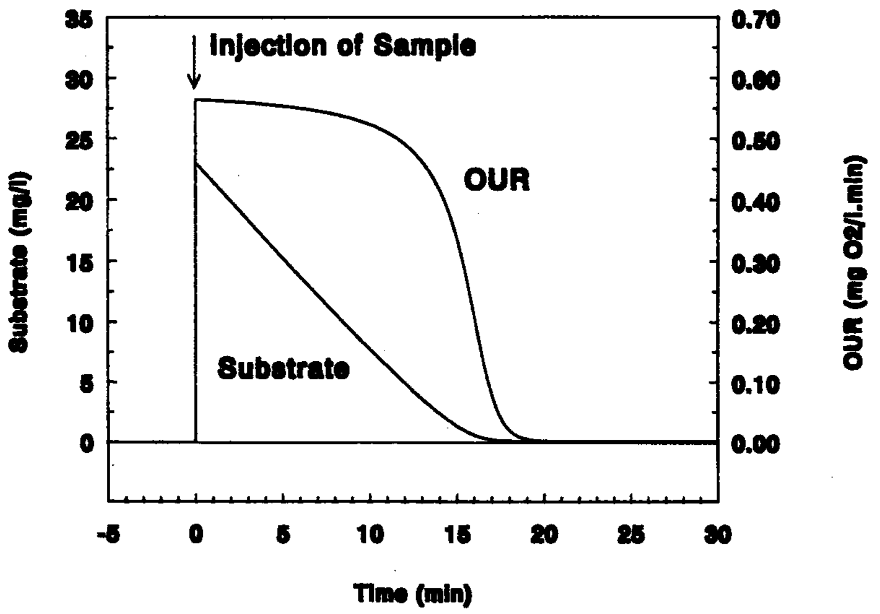
	Wastewater Copper Concentration			
	0.0	1.0	2.0	4.0
PS	0.57	0.44	0.19	0.02
PH	2.20	1.81	0.80	0.38
PA	18.6	16.7	17.0	17.5
C_o	7.22	7.20	7.45	7.63
Time	20.1	22.9	36.3	64.0

Respirograms: Background

Pollutant = Substrate → Y → New Biomass

Pollutant = Substrate → 1-Y → + Oxygen -> CO_2,NO_3,...

Oxygen Uptake Rate = (1-Y)*Substrate Degradation Rate

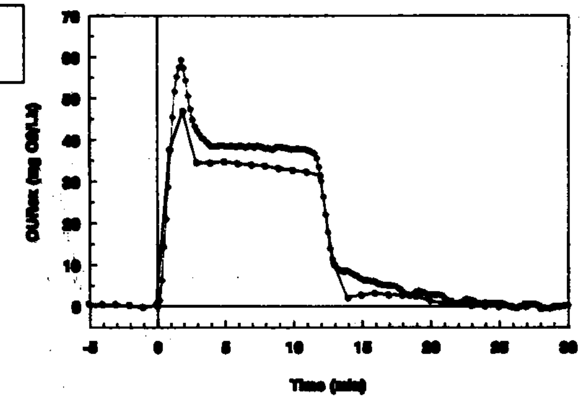


Aim: Characterize Biodegradation of Pollutants via Interpretation of recorded OUR profiles

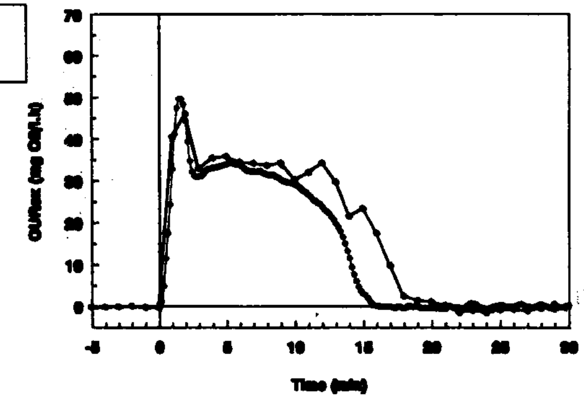
WATER 1

Method 1
Method 2

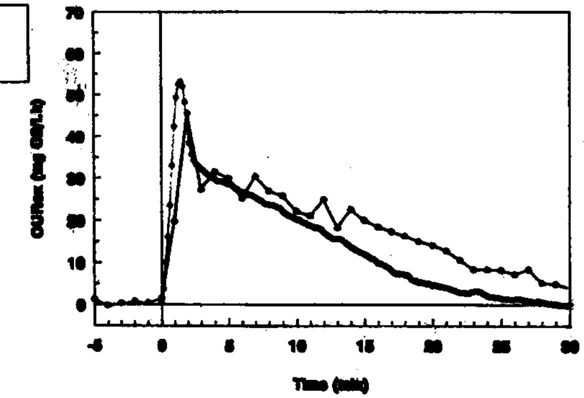
Sludge 1



Sludge 2

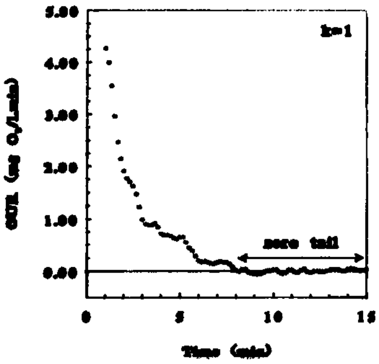


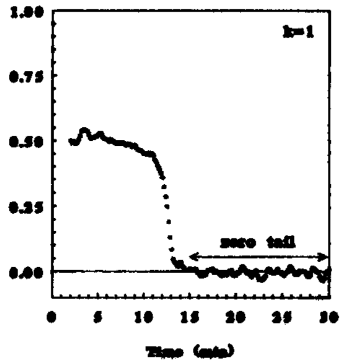
Sludge 3

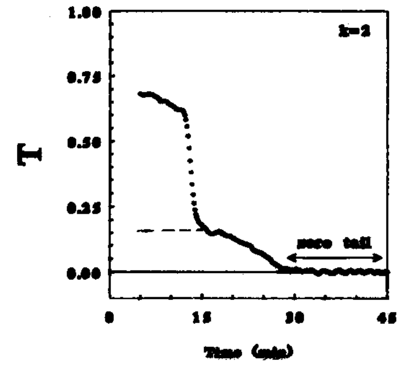


Candidate Biodegradation Models

Exponential	Single Monod	Double Monod
$r_{s1} = \frac{\mu_1 X}{Y_1} S_1$	$r_{s1} = \frac{\mu_1 X S_1}{Y_1(K_{s1}+S_1)}$	$r_{s1} = \frac{\mu_1 X S_1}{Y_1(K_{s1}+S_1)}$ $\quad r_{s2} = \frac{\mu_2 X S_2}{Y_2(K_{s2}+S_2)}$
$\frac{dS_1}{dt} = -r_{s1}$	$\frac{dS_1}{dt} = -r_{s1}$	$\frac{dS_1}{dt} = -r_{s1}$ $\quad \frac{dS_2}{dt} = -r_{s2}$
$OUR_{ex} = (1-Y_1).r_{s1}$	$OUR_{ex} = (1-Y_1).r_{s1}$	$OUR_{ex} = (1-Y_1).r_{s1} + (1-Y_2).r_{s2}$







Application of On-line Modelling with In-Sensor-Experiments (Kong, 1994)

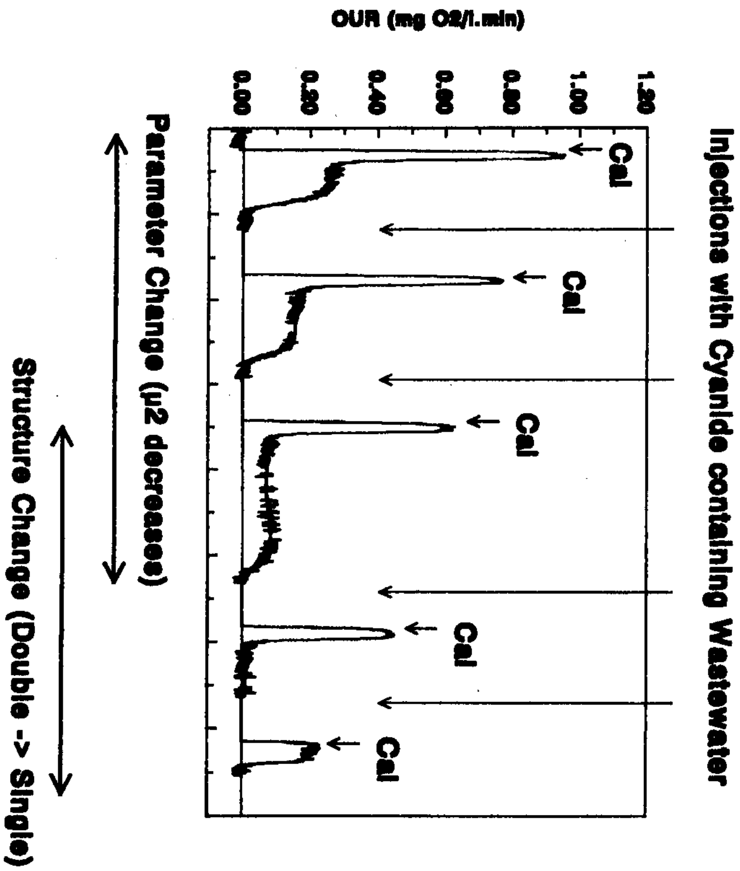
Simultaneous Characterization of :

- Aerobic Carbon-oxidation Capacity
- Nitrification Capacity

of the Sludge

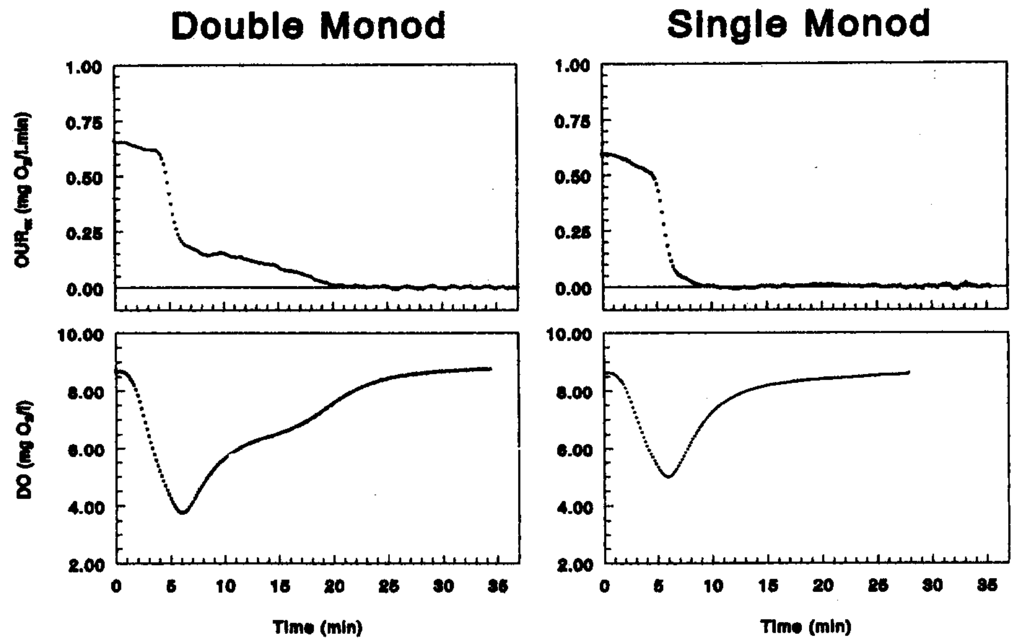
Principle:

Calibrate with Mixture of C-source/NH_4Cl (Double Monod)



Mathematical Models

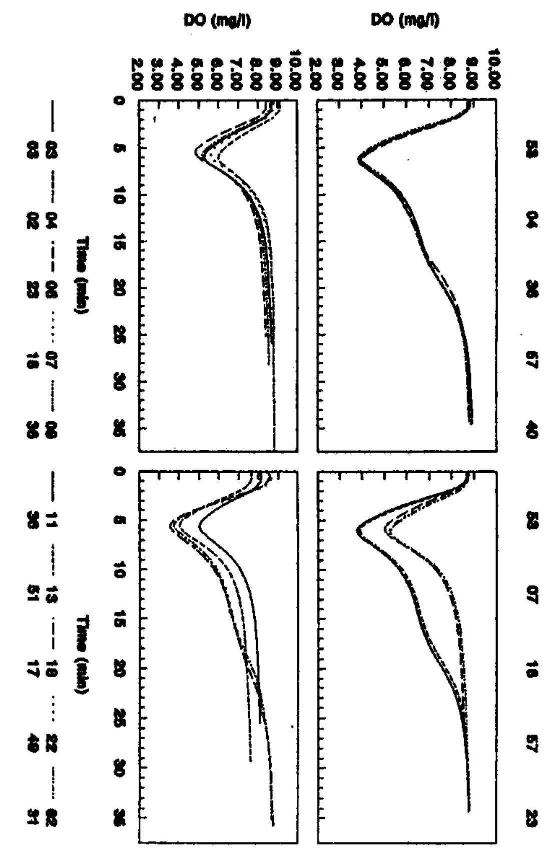
Typical Results:



Results

Toxicity Event A2 (February 17-20 1994)

Raw Data (20 respirograms)



Visual Inspection:

Toxicity detected: 18/2/94 at 17:18

Recovery observed: 19/2/94 at 18:17

Automation ?

On-line Model Identification

-> Parameter change

-> Model Structure change

Model selection

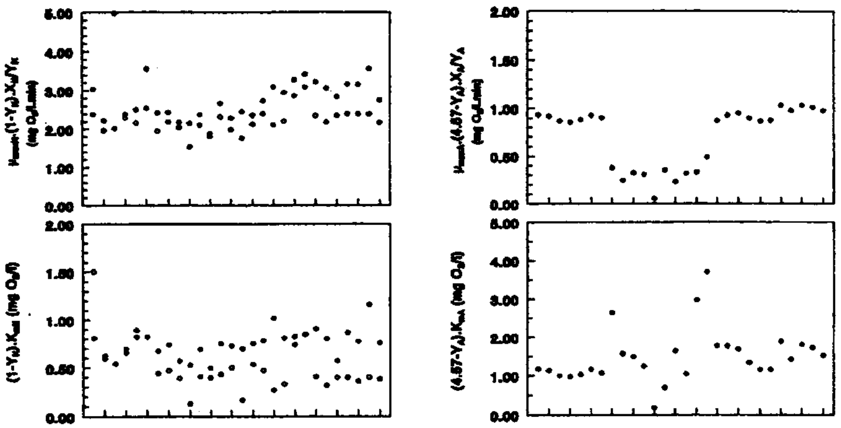
- Fit: MSE = J/(n-p)
- Fit/Complexity: AIC = n.log(J/n) + 2p
- Residuals Analysis: Runs

Detection in due time ! => On-line ! => fast NPC

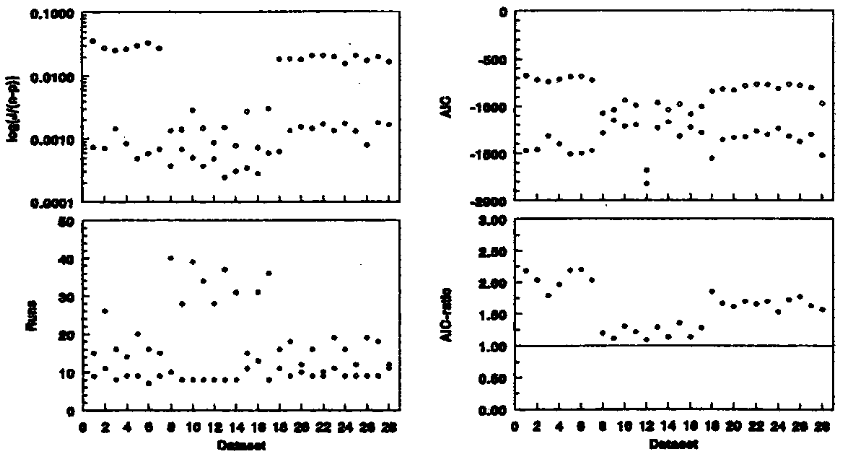
Results
(continued)

Parameters:

Heterotrophs (Acetate) Autotrophs (ammonia)



Model Selection:

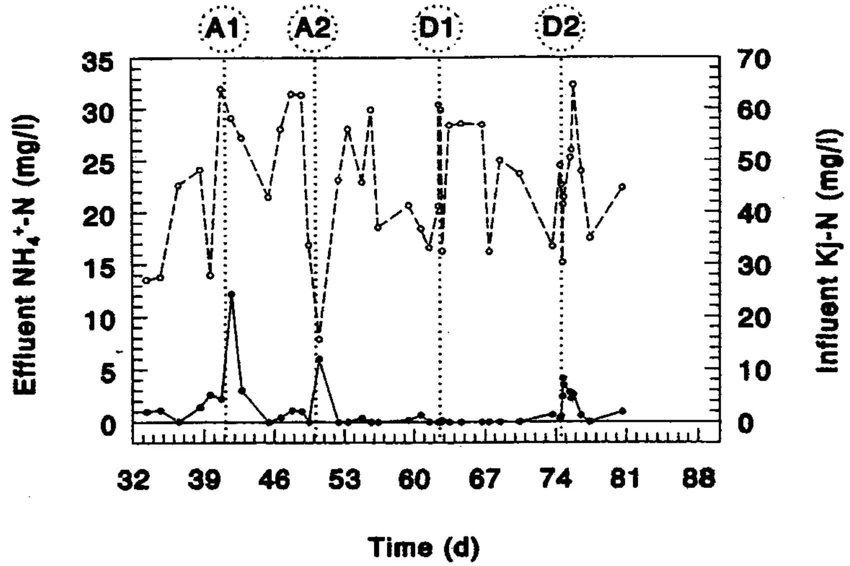


Results

Two month evaluation period:

RODTOX Detection of
- 2 accidental intoxications A1,A2
- 2 deliberate intoxications D1,D2

Effect on Nitrogen Oxidation:



Deliberate intoxications with creoline (IC_{20}=7.5; IC_{50}=40 ppm)

Procedure:

D1: Creoline addition stopped after alarm => PROTECTION !
=> Concentration in Aeration tank = 5 ppm

D2: Addition of Creoline continued after toxicity alarm
=> Concentration in Aeration tank = 25 ppm
=> Effluent ammonia increases to 5 ppm