Three Stages Membrane Bioreactor
(Methanogenic, aerobic biofilm and filtration)
For the Treatment of Municipal Wastewaters

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Tlemcen University,
Tuesday 9th February

Index

Introduction: Development of the idea

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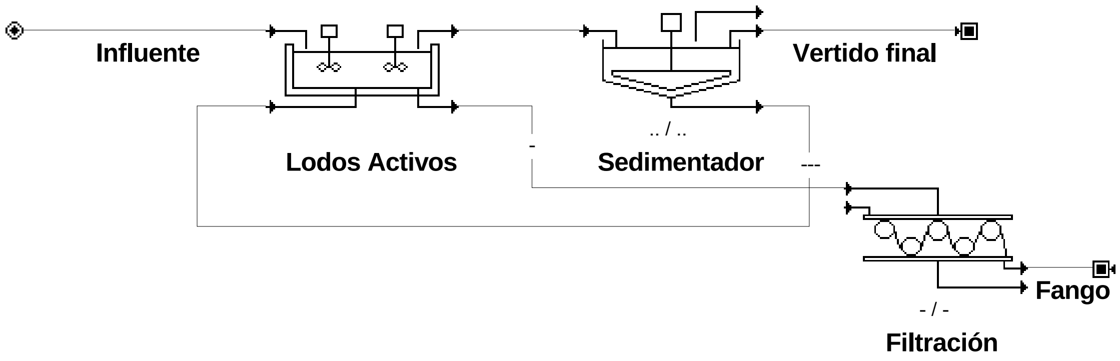
Main Objective:

Proposal European Project SAWRA, Call for Africa:

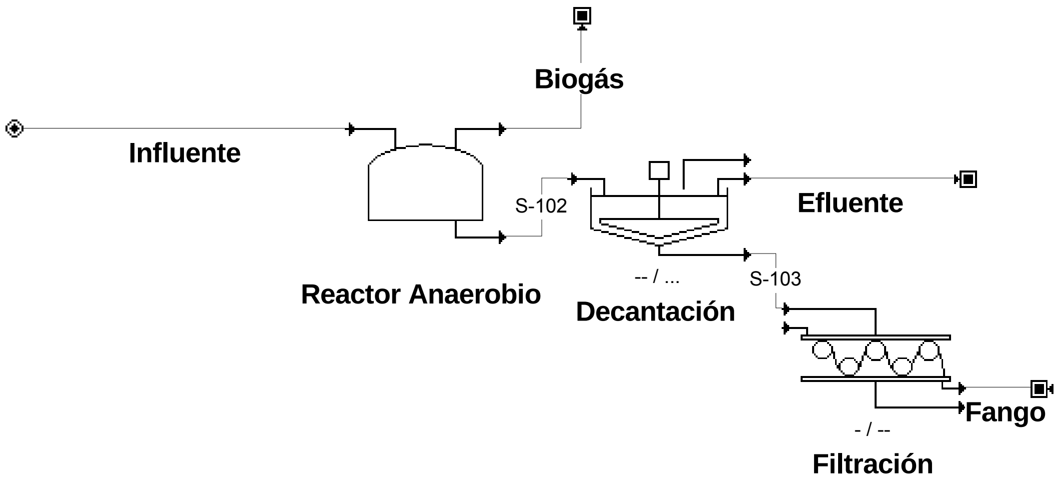
This project is aimed at exploring the applicability of **anaerobic bioreactors** with highly **efficient solid/liquid separation** and run at **ambient temperature** for **wastewater reuse** in agriculture by increasing its reliability and reducing treatment costs.

Wastewater treatment process

Simplified system of aerobic treatment



Simplified system of anaerobic treatment



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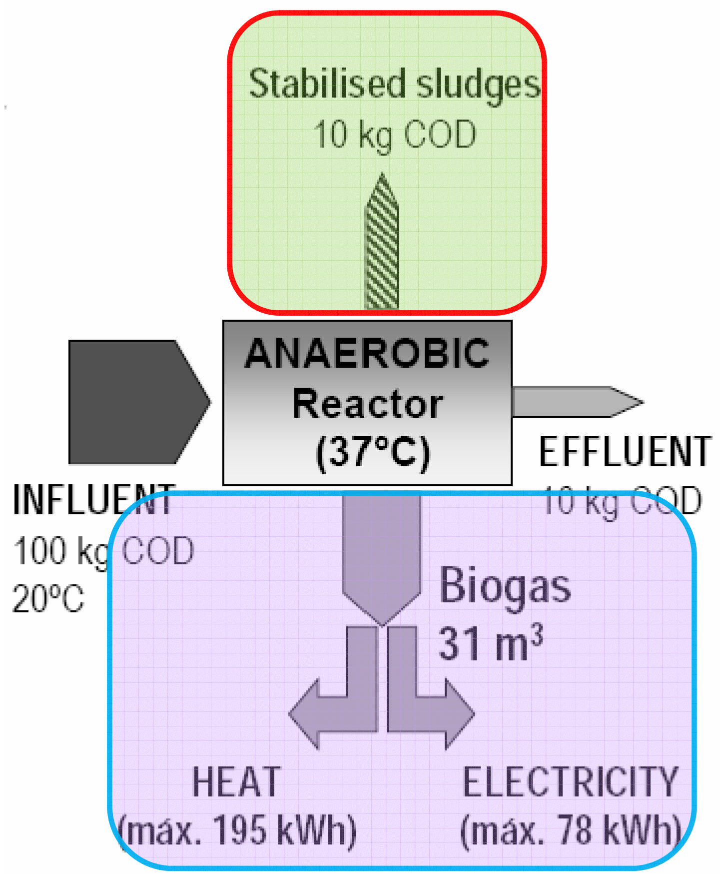
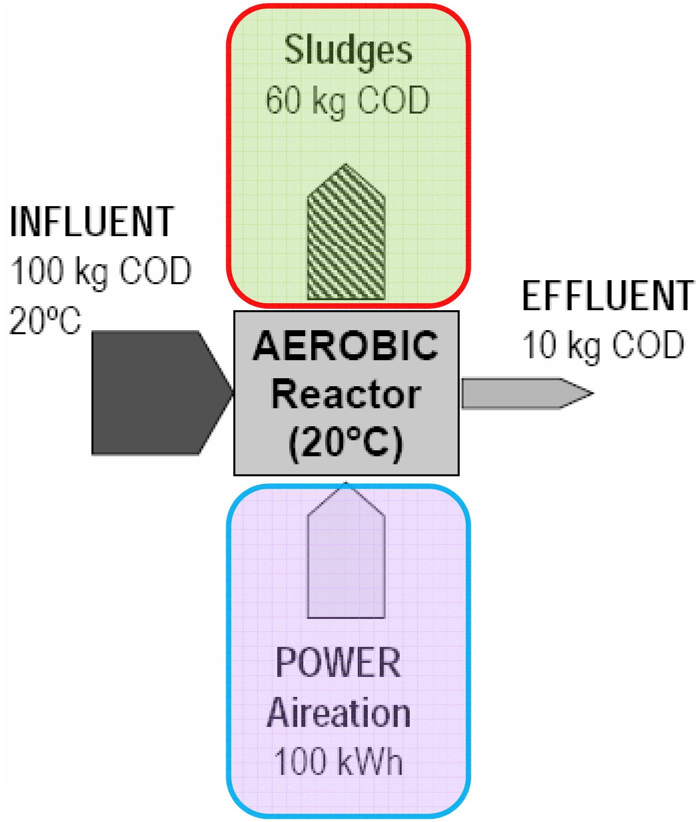
Wastewater treatment process – balances

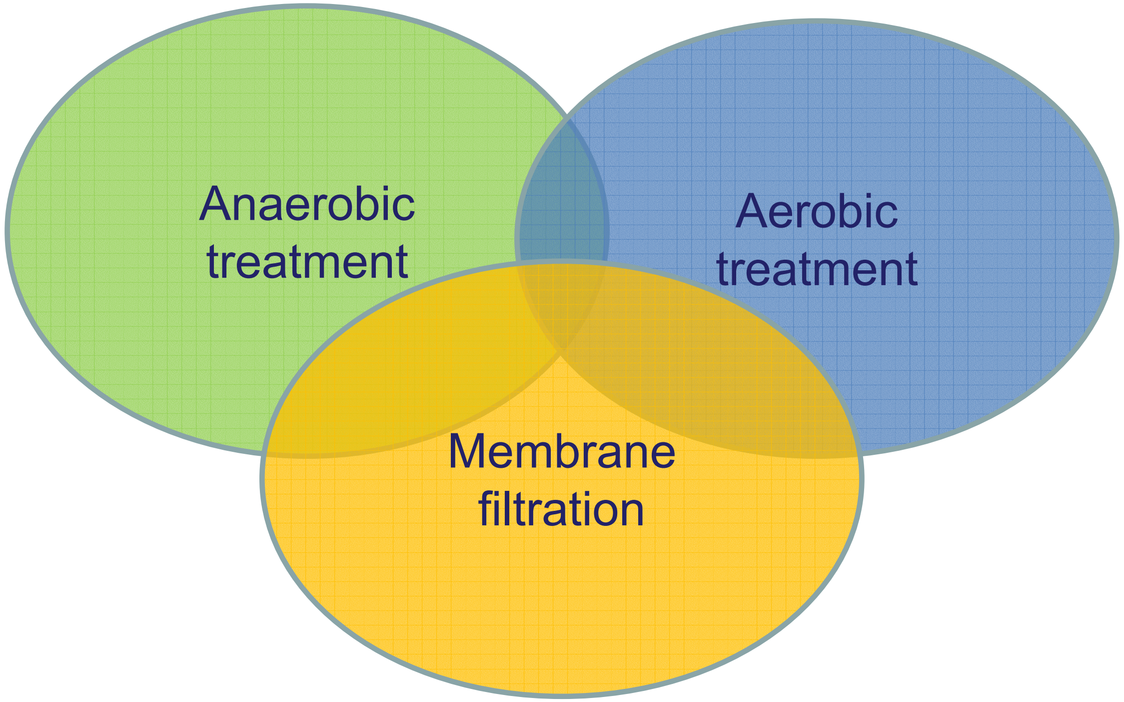




Capacity and Efficiency of Anaerobic Reactors

Reactor	Volume (L)	T (°C)	HRT (h)	COD influent	Elimination (%) COD	SS	Reference
EGSB	120	>13	1-2	391	16-34	-	Van der Last and Lettinga (1992)
UASB	2	20	5-24	220-985	53-85	63-89	Ruiz et al. (1998)
UASB	8	6-20	3-48	350-600	38-85	50-87	Singh and Viraraghavan (1999)
UASB	46	28	4-8	297-463	68-76	73-78	Gonçalves et al. (1999)
UASB	9000	28	7,5	-	80	90	Chernicharo y Cardoso (1999)
UASB	21.5	13-19	4,7	115-595	64-72	73-84	Uemura and Harada (2000)
UASB	3.8	13	8	456	65	88	Elmitwalli et al. (1999)
RH	3.8	13	8	456	66	92	Elmitwalli et al. (1999)
UASB	3.5	9-15	12	310	37-48	-	Bodick et al. (2000)
UASB	416	28	4	511	71	66	Chernicharo y Nascimento (2001)
UASB	150	21	6	569	71	79	Torres y Foresti (2001)
UASB	23	29	3,9	320	65	76	Kalogo et al (2001)
UASB	416	28	4-6	558-958	77-86	78-94	Von Sperling (2001)
UASB	64000	25	6	267	63	-	Lettinga (2001)
UASB	12000[a]	27	6	-	54	65	Wiegant (2001)
UASB	810[a]	30	9,3	427	72	56	Florencio et al. (2001)
RH	88	13	4	518	34	53	Elmitwalli et al. (2002)
EGSB	157.5	30.5	4	126-180	43-48	59-82	Kato et al. (2003)
UASB	140	15	6	721	44	73	Mahmoud et al. (2004)
UASB	54	10-28	13,5	750	48-82	-	Lew et al. (2004)
UASB	60000	18-25	23-27	1500	51-62	50-55	Halalsheh et al. (2005)
UASB	120	27	1-6	92-716	37-60	65-96	Leitao et al. (2005)
UASB	25500	13-15	10-11	330	54-58	75-85	Álvarez et al. (2006)
UASB	17	10-27	24	325	51-68	73-85	Sumino et al. (2007)

Present work – the development



Present work – the concept

Anaerobic treatment + **Aerobic treatment** + **Membrane filtration**

Anaerobic treatment:
→ Biogas production
→ Energy savings
→ Low sludge production

Aerobic treatment:
→ High effluent quality
→ High membrane fluxes

Membrane filtration:
→ Total retention of microorganisms
→ Elevated quality of effluent (reuse)

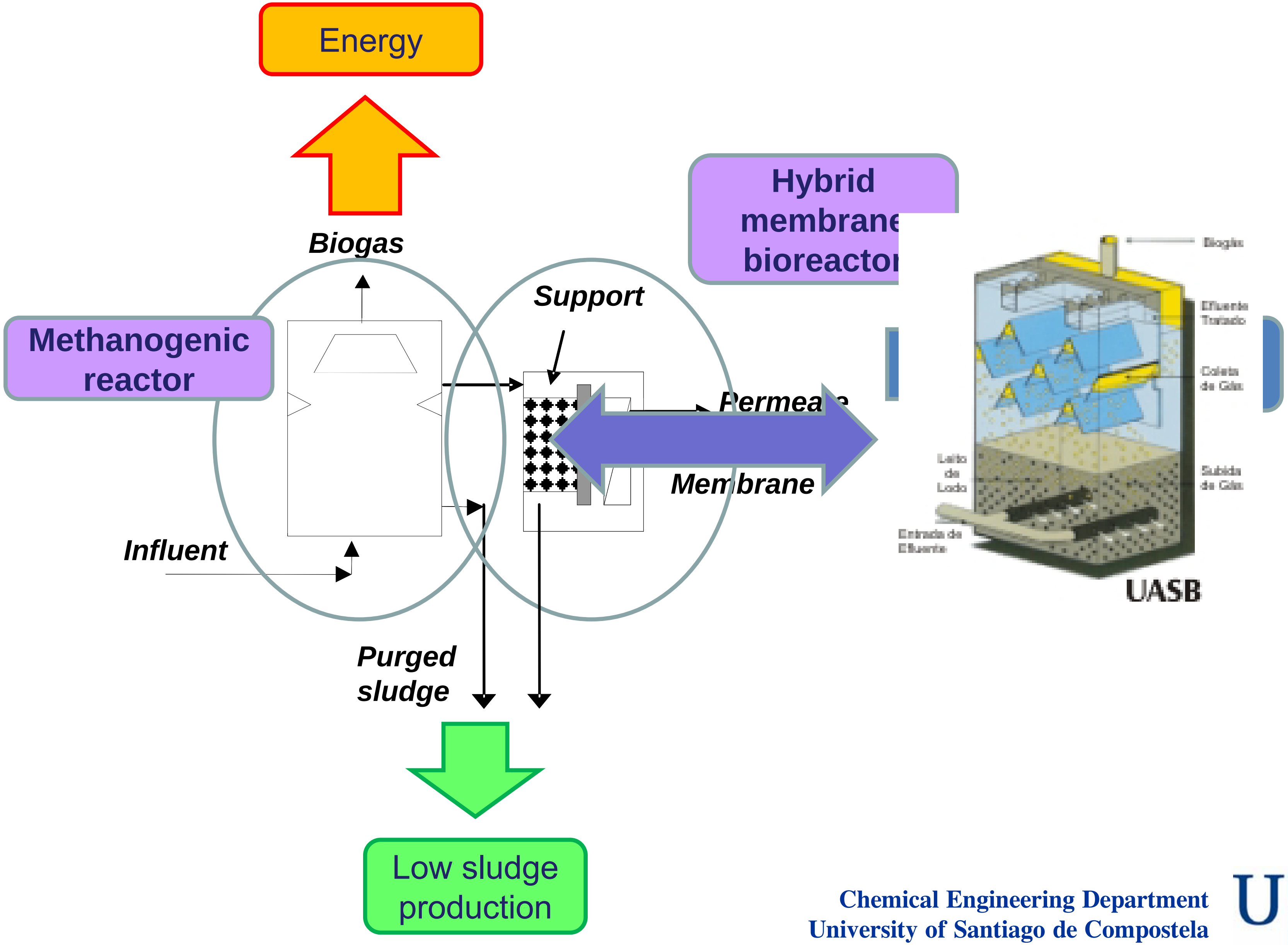
Direct reuse

- Agriculture
- Sulviculture
- Gardening

Non-sensible zones

- Nutrient elimination not required
- Small or medium locations

Present work – the concept



Support: Kaldness K-3

Pilot Plant design and strategy of operation

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Considerations for the design of the reactor

Average Sewage:
COD Influent: 500 mg/L
Flow rate: 480 L/d
Organic Load: 240 g/d

Anaerobic reactor:
Organic Loading Rate (15 ºC; 30% SS): 1.5- 2.0 kg/m3·d
Percentage COD removal: 70 %
Volume anaerobic chamber: Van= OL/OLR= 240/2 = **120 L**

Aerobic chamber:
Organic Load to the aerobic chamber: 0.3*240= 72 g COD/d
Organic Loading Rate: 2 kg/m^3·d (Leiknes 2008; Our research)
Volume aerobic biofilm chamber: Vae= 72/2 = **36 L**
Volume filtration chamber (ZW-10)= 20 L
Support hold-up: 20-30% (v/v)
Volume of support: 14.4 - 21.6 L

Overall Hydraulic Retention Time: (120+56)/480 = 0.4 d (9.0 h)

Considerations for the design of the reactor

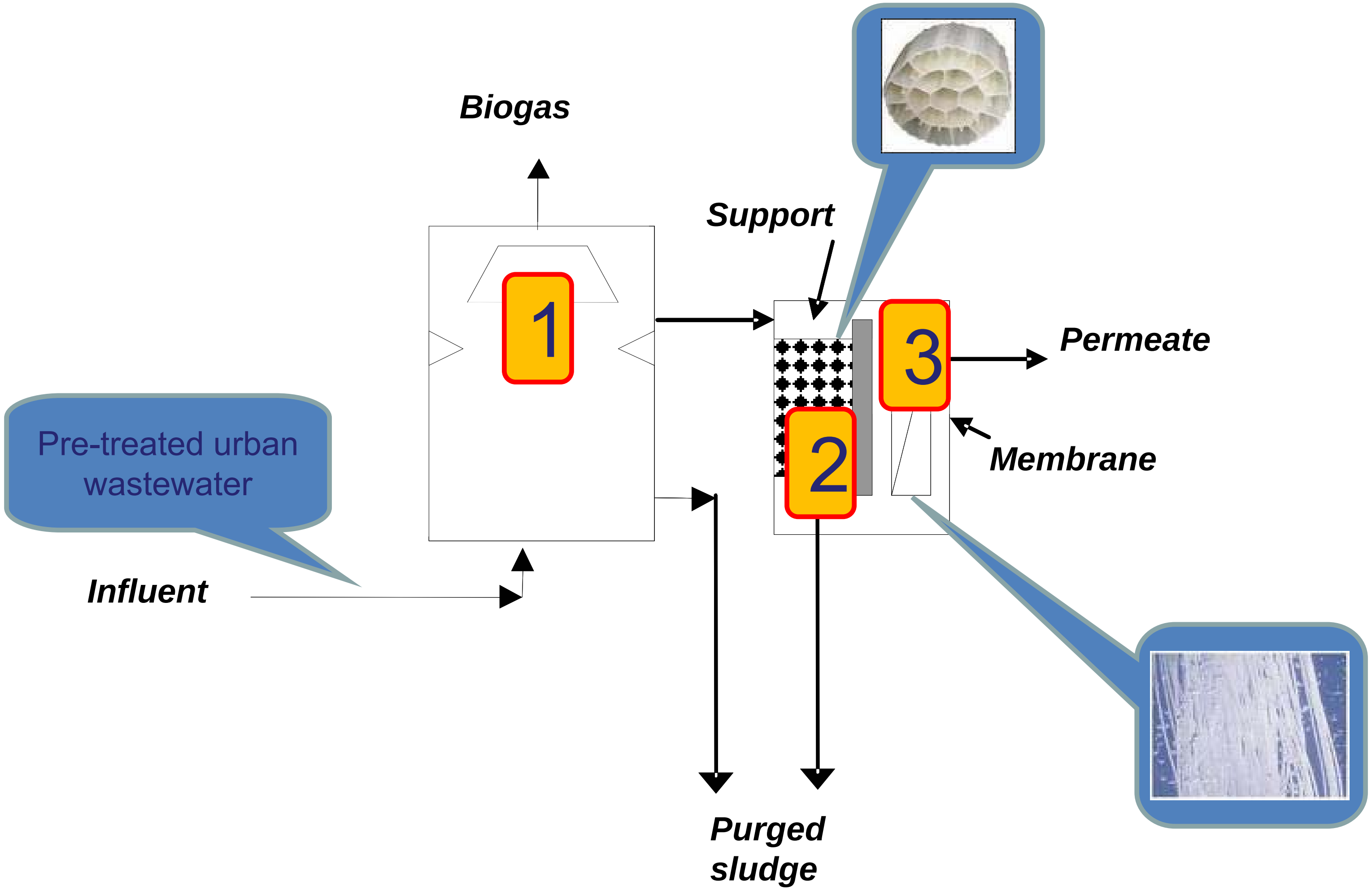
Strong Sewage as influent
COD Influent: 1000 mg/L
Flow rate: 480 L/d
Organic Load: 480 g/d

Anaerobic reactor:
Organic Loading Rate (15 ºC; 30% SS): 1.5- 2.0 kg/m3·d
Percentage COD removal: 70 %
Volume anaerobic chamber: Van= OL/OLR= 480/2 = **240 L**

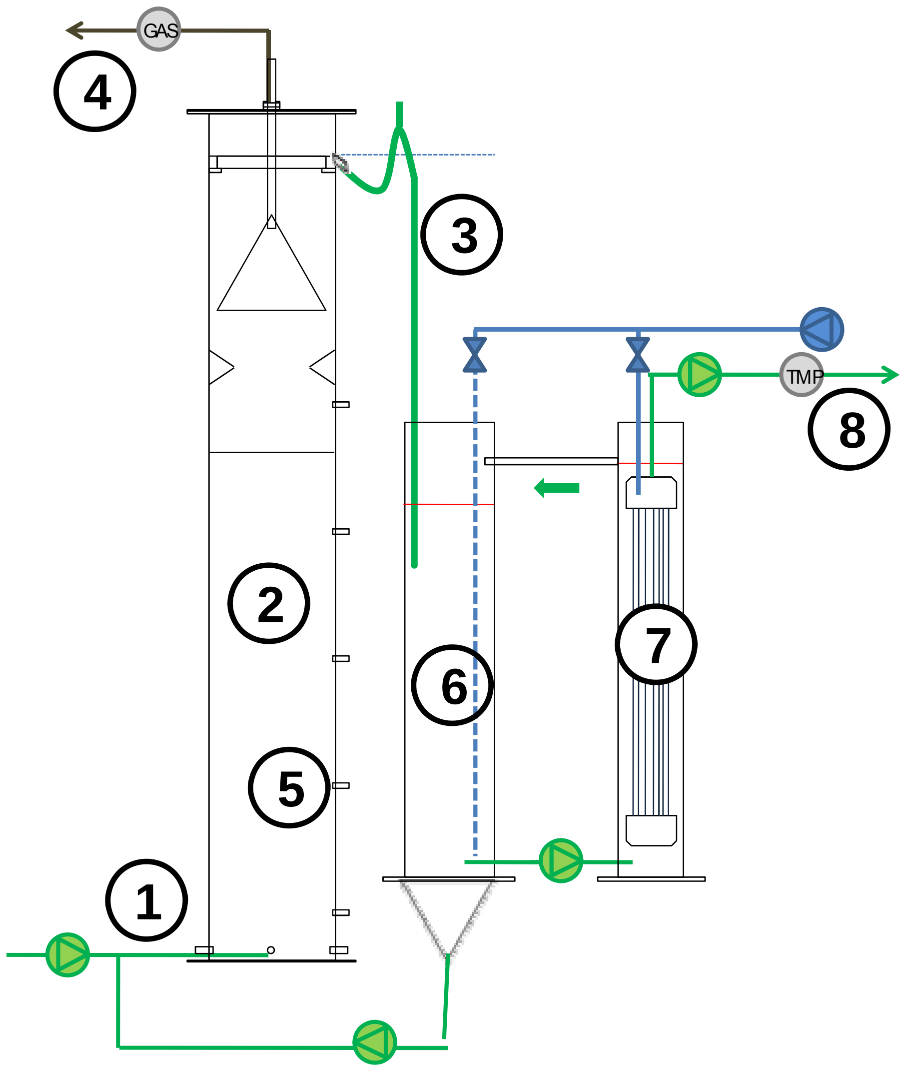
Aerobic chamber:
Organic Load to the aerobic chamber: 0.3*480= 144 g COD/d
Organic Loading Rate: 2 kg/m^3·d
Volume aerobic chamber: Vae= 144/1= **144 L**
Support hold-up: 20-30% (v/v)
Volume of support: 28.8 - 43.2 L

Overall Hydraulic Retention Time: (240+144)/480 = 0.8 d (19.2 h)

Considerations for the design of the reactor



Pilot Plant, Three Stages MBR



UASB	SMBR	FU
UPFLOW ANAEROBIC SLUDGE BLANKET REACTOR	SUPPORT MEMBRANE BIOREACTOR	FILTRATION UNIT
120 L	36 L	20 L

1. INFLUENT
2. UASB REACTOR
3. EFFLUENT FROM UASB REACTOR
4. BIOGAS OUTLET
5. SAMPLING PORTS
6. AEROBIC CHAMBER WITH SUPPORT
7. FILTRATION UNIT
8. PERMEATE

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Pilot Plant, Three Stages MBR

1 Methanogenic Chamber
2 Aerobic Biofilm Chamber
3 Membrane Filtration Chamber

Pilot Plant, Three Stages MBR

Operation strategy

1.- Start-up the reactor with a “synthetic wastewater free of solids” with a similar COD than Sewage (1000 mg/L). Study the effects of Temperature on efficiency and membrane fouling (12 months)

Reactor fed with skimmed milk diluted in tap water

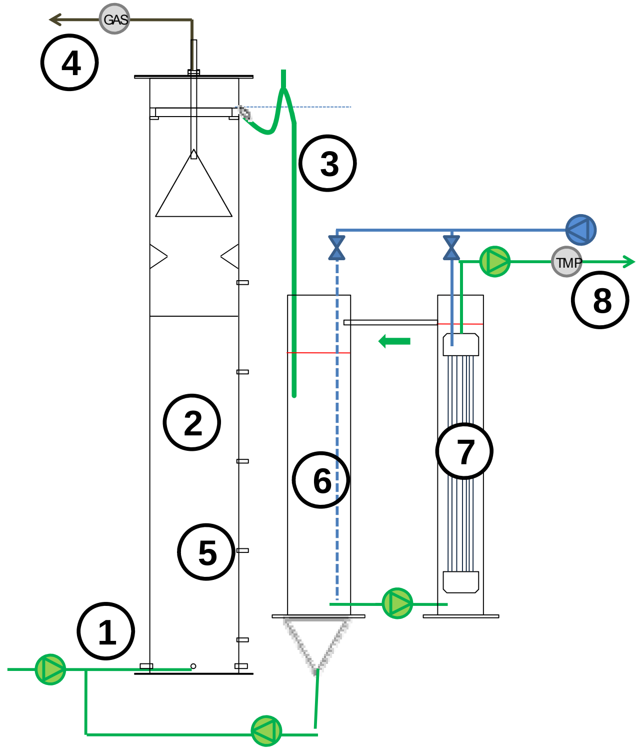
2.- To use a “synthetic wastewater” with suspended organic matter. (3 months)

3.- To use pre-settled municipal wastewater. It is important to use micro-sieves with round openings of 0.8 – 1.0 mm. (3 months)

4.- To use degritted municipal wastewater. It is important to use micro-sieves with round openings of 0.8 – 1.0 mm. (3 months)

Operation strategy

ANALYSIS	1	2	3	4	5	6	7	8
Standard								
Temperature	daily	daily				daily		
pH	daily	daily				daily		
Alkalinity			daily					
DO						daily		
COD_{total}	3 x week		3 x week					3 x week
$COD_{soluble}$	3 x week		3 x week					
BOD_{total}	3 x week		3 x week					3 x week
NTK	3 x week		3 x week					3 x week
TOC (IC, TC, TOC)			3 x week				3 x week	3 x week
Anions Kations	3 x week		3 x week					3 x week
VFA			3 x week					
Solids								
TSS					3 x week	3 x week		
VSS					3 x week	3 x week		
SMA		monthly						
Biogas								
Q_{gas}				daily				
Composition				3 x week				
Membrane								
Pressure							daily	
Filterability							NO	
Flux							NO	
ANALYSIS	1	2	3	4	5	6	7	8



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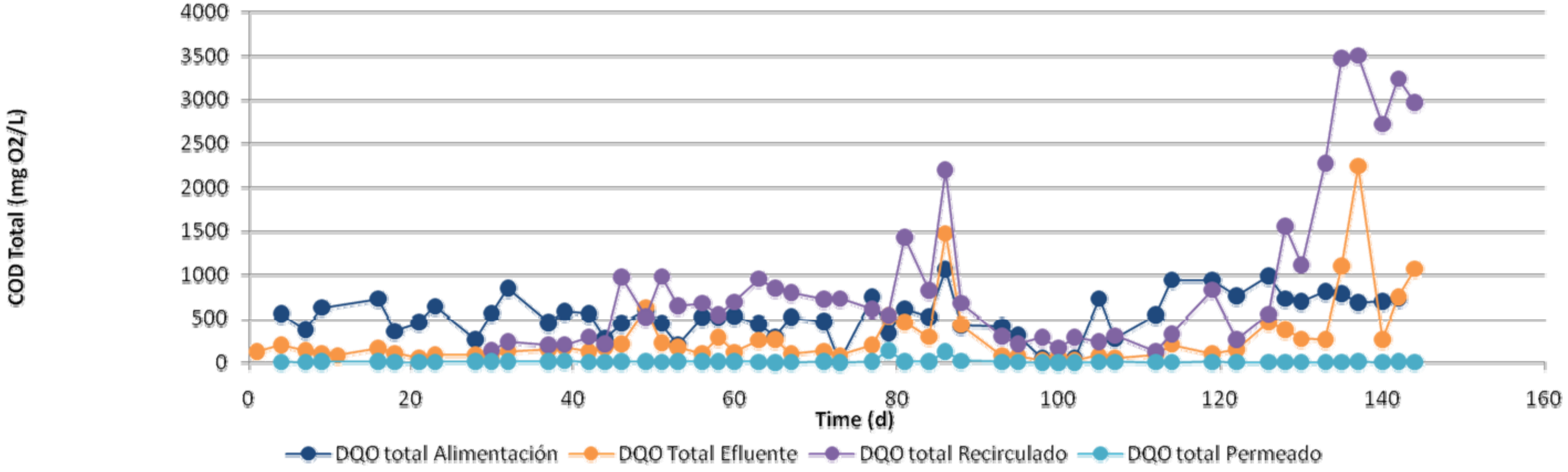
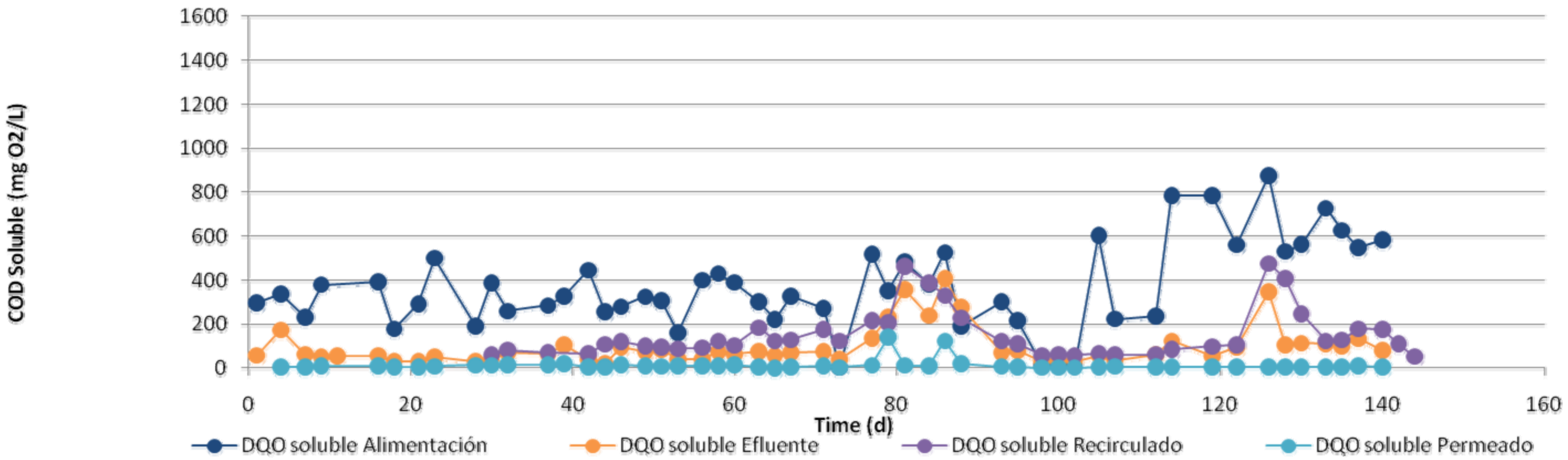
Results: Liquid Phase

COD removal

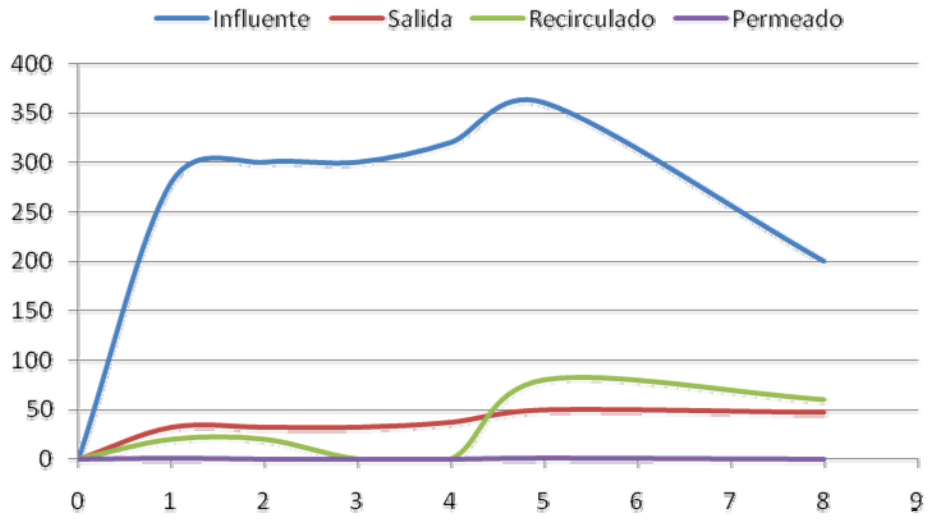


4000
3500
3000
2500
2000
1500
1000
500
0
COD Total (mg O2/L)
0
20
40
60
80
100
120
140
160
Time (d)
DQO total Alimentación
DQO Total Efluente
DQO total Recirculado
DQO total Permeado

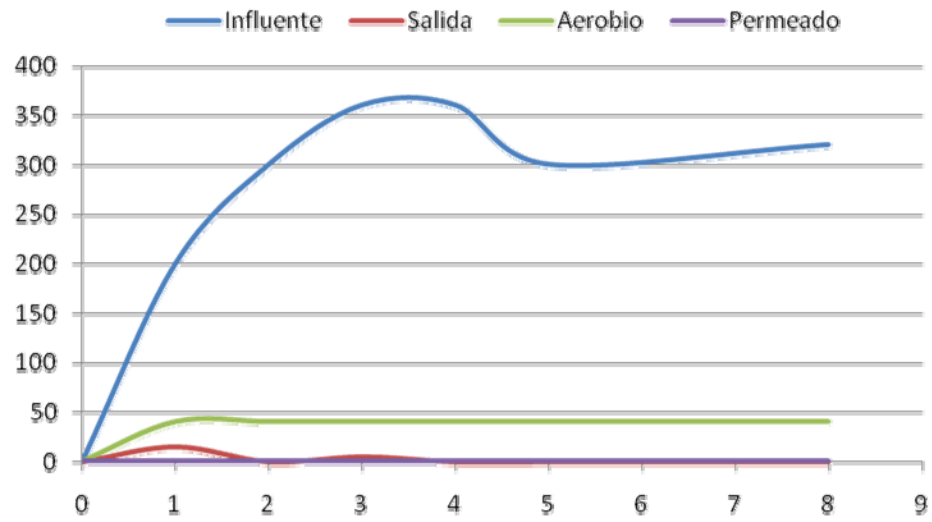


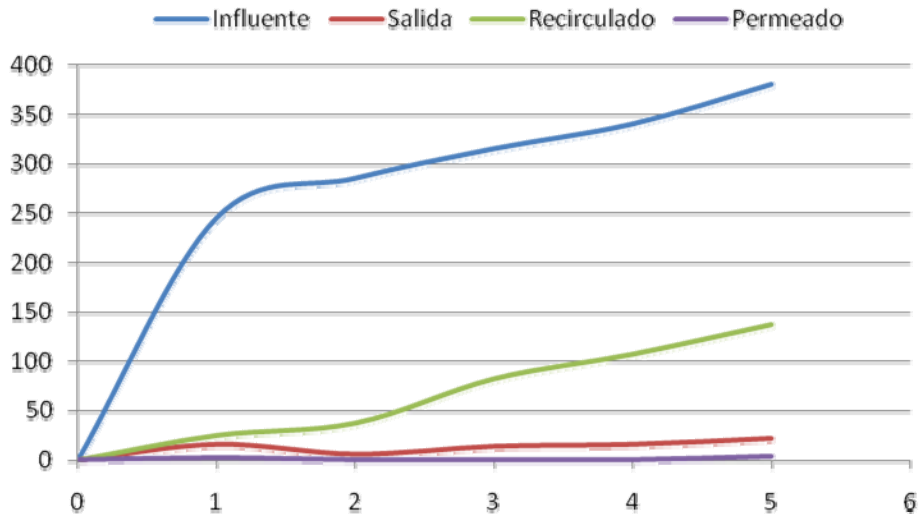
1600
1400
1200
1000
800
600
400
200
0
COD Soluble (mg O2/L)
0
20
40
60
80
100
120
140
160
Time (d)
DQO soluble Alimentación
DQO soluble Efluente
DQO soluble Recirculado
DQO soluble Permeado

BOD$_5$



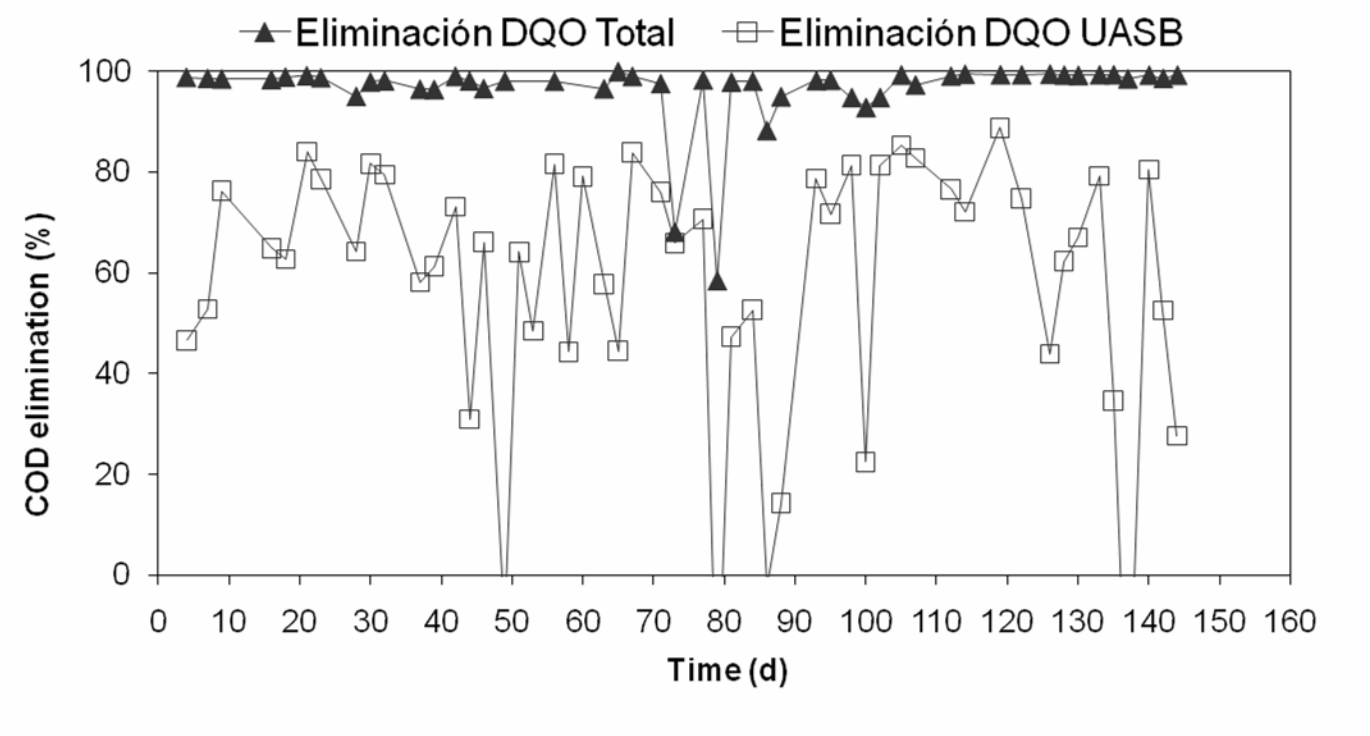
18-23.11.2009



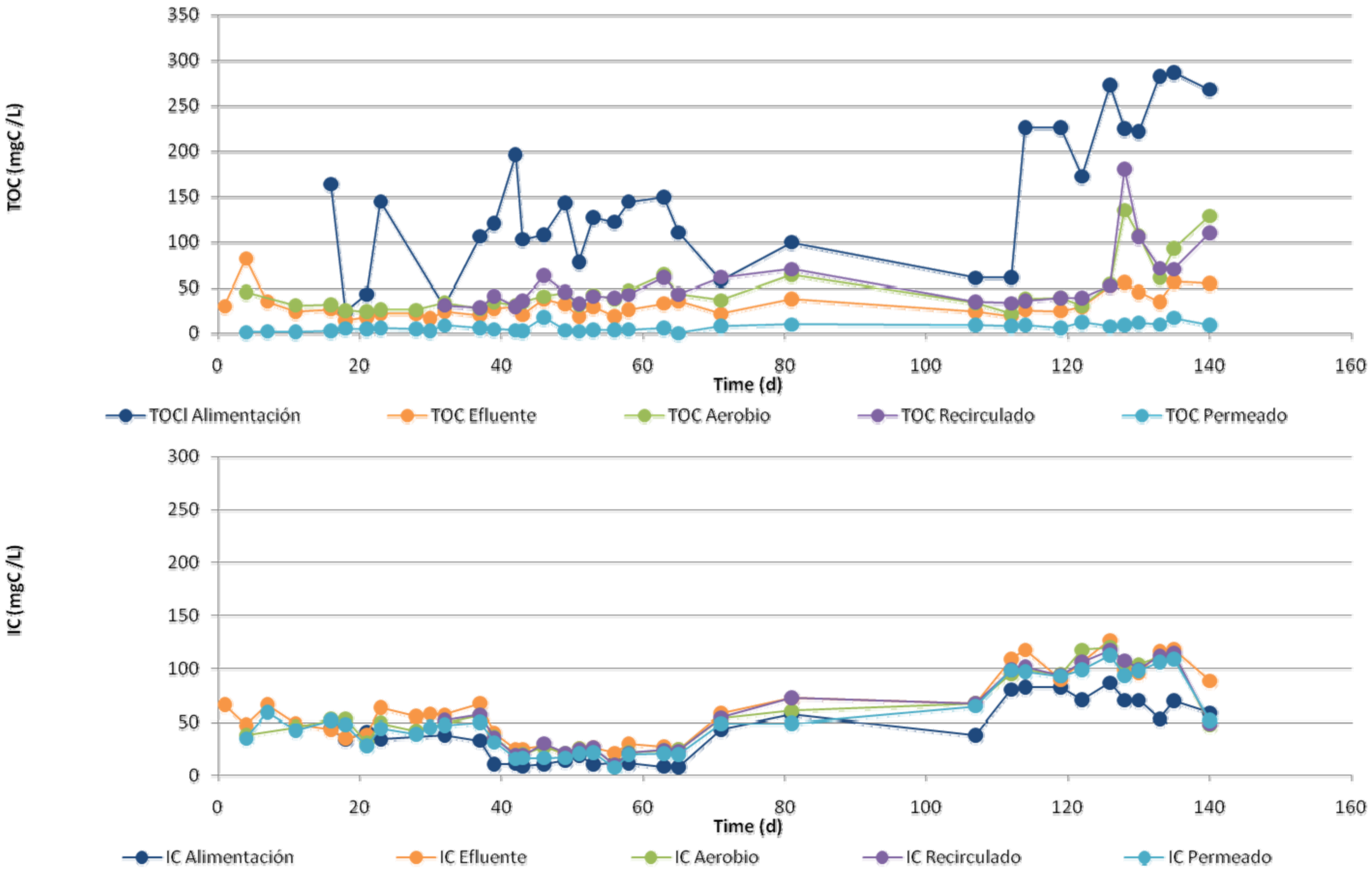


11-16.12.2009

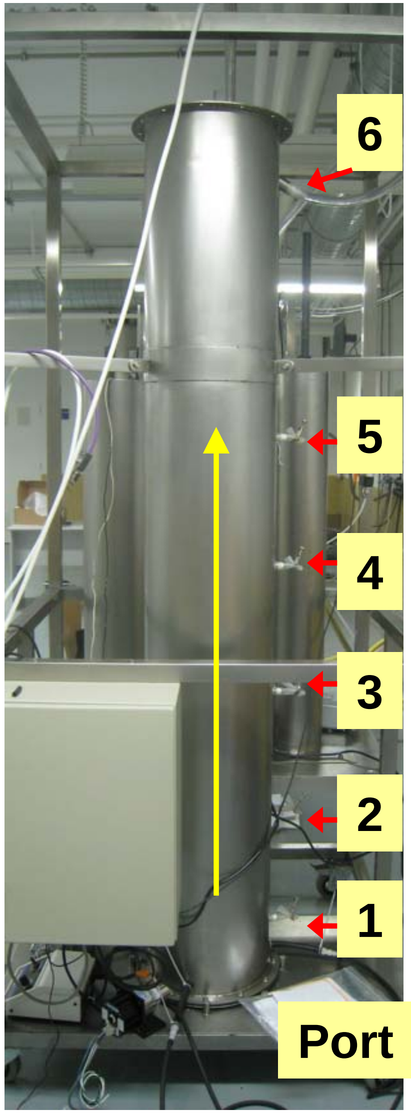
COD removal

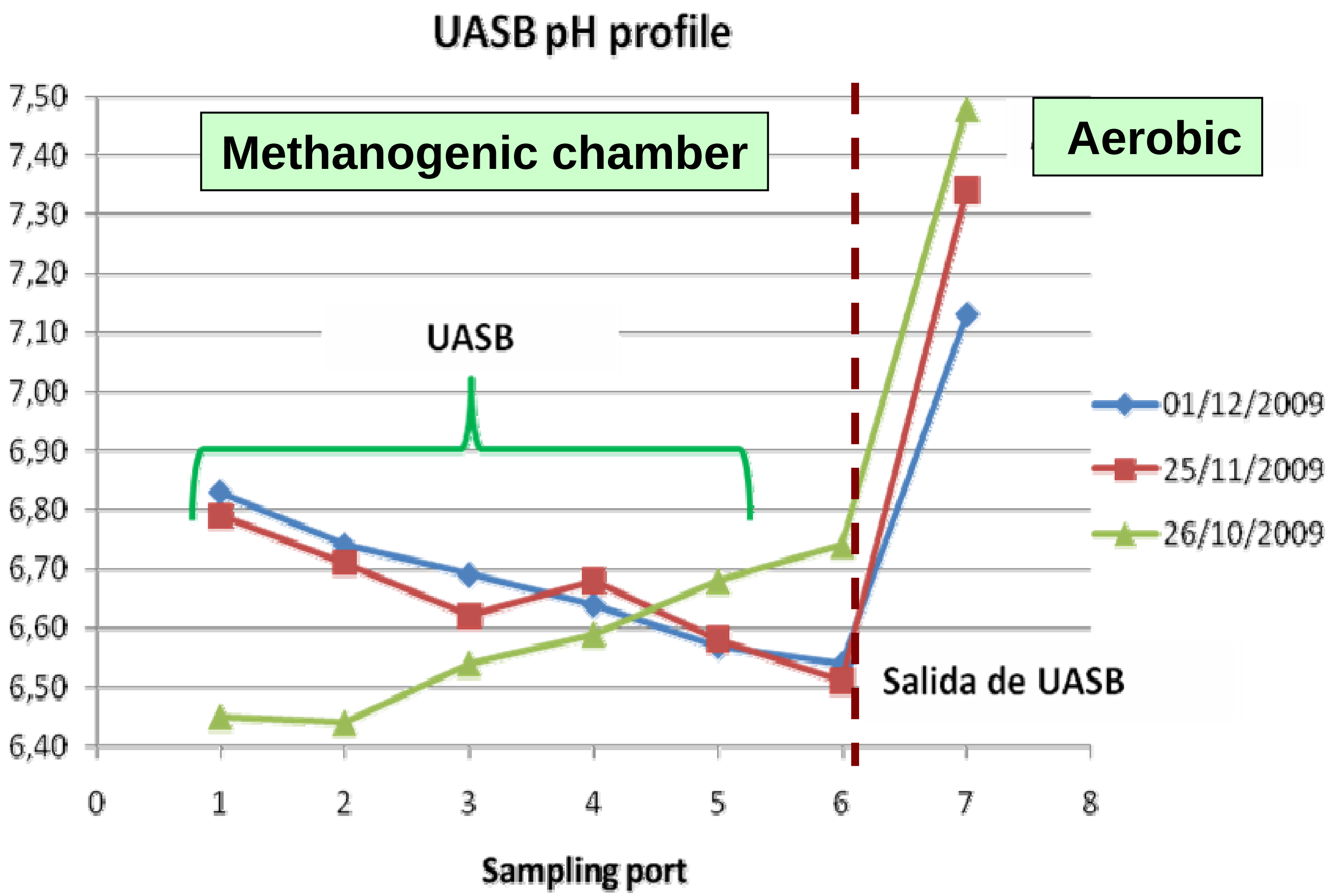

Eliminación DQO Total
Eliminación DQO UASB
COD elimination (%)
Time (d)
0
20
40
60
80
100
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160

Dissolved Carbon: Organic (DOC) and Inorganic (IC)



pH profile





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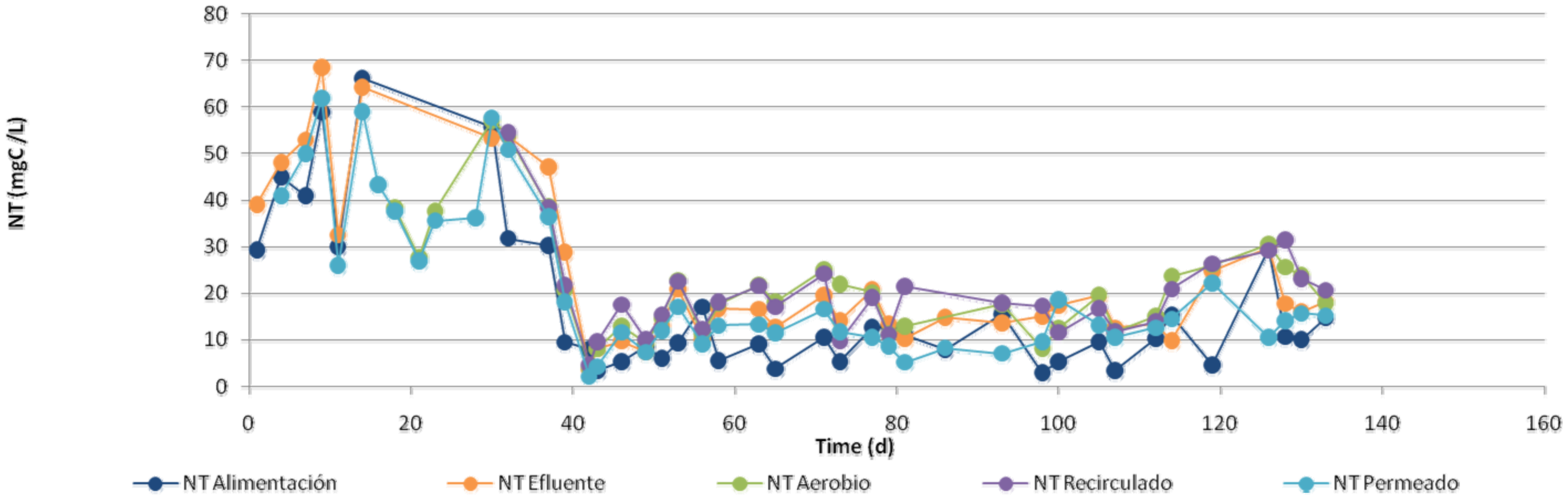
Total Nitrogen (TN)



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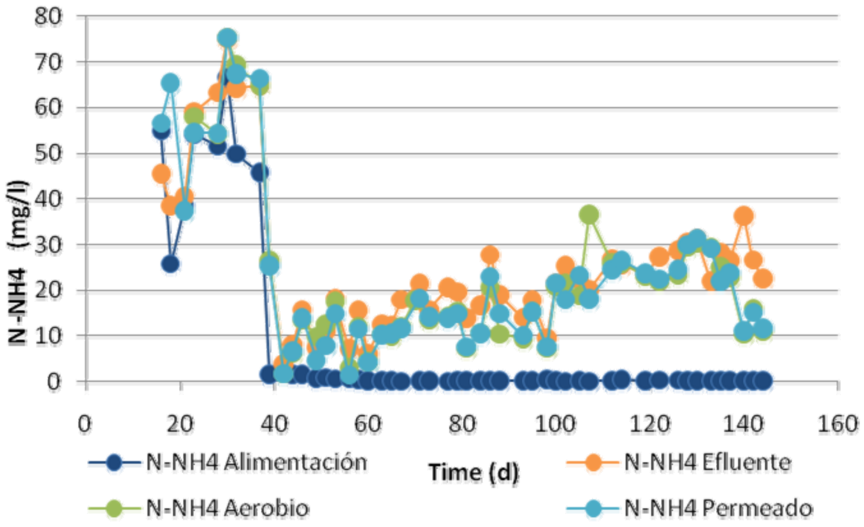
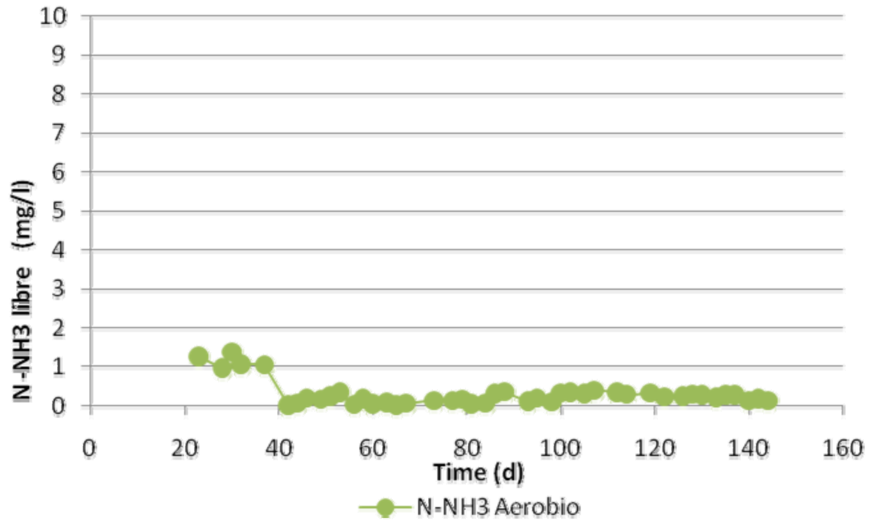
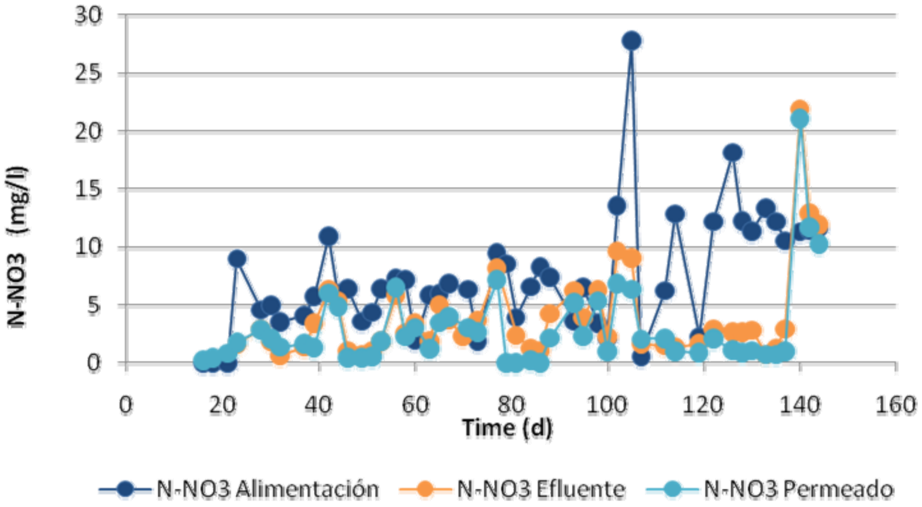
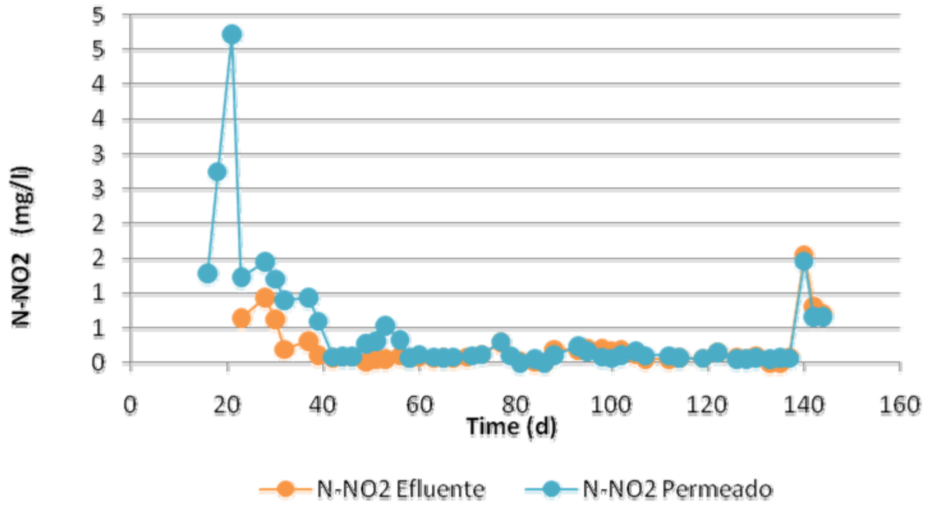
Nitrogen compounds

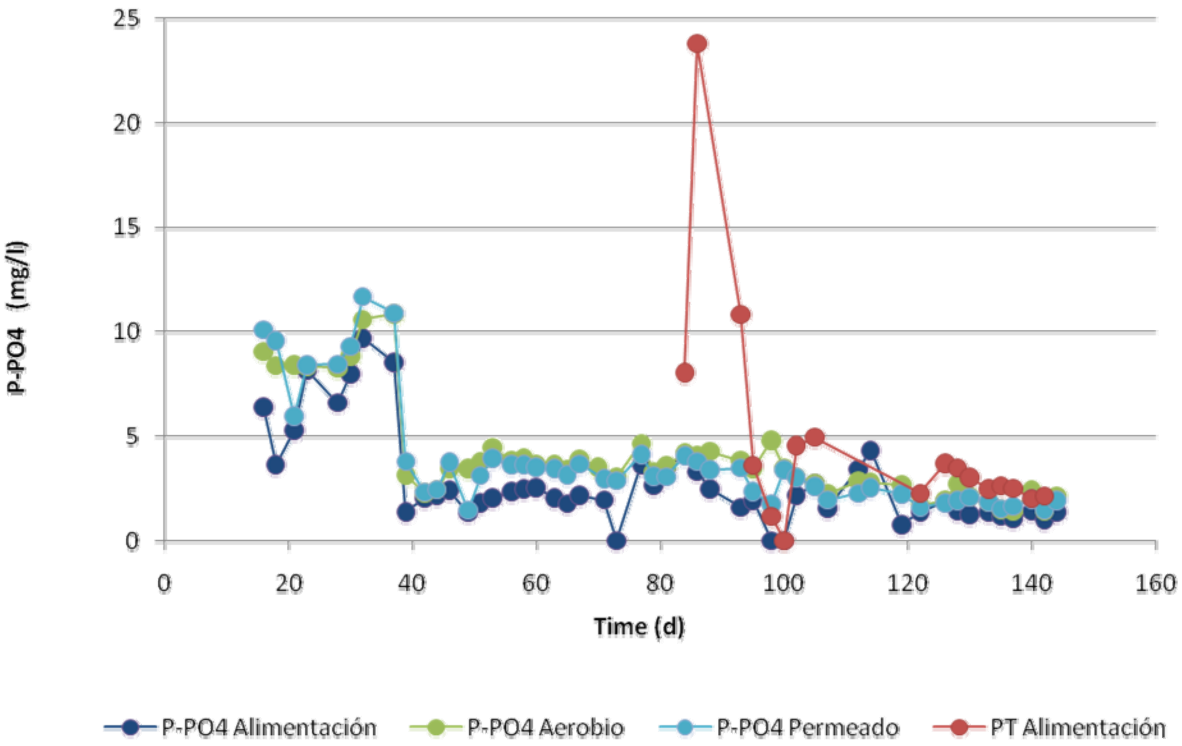




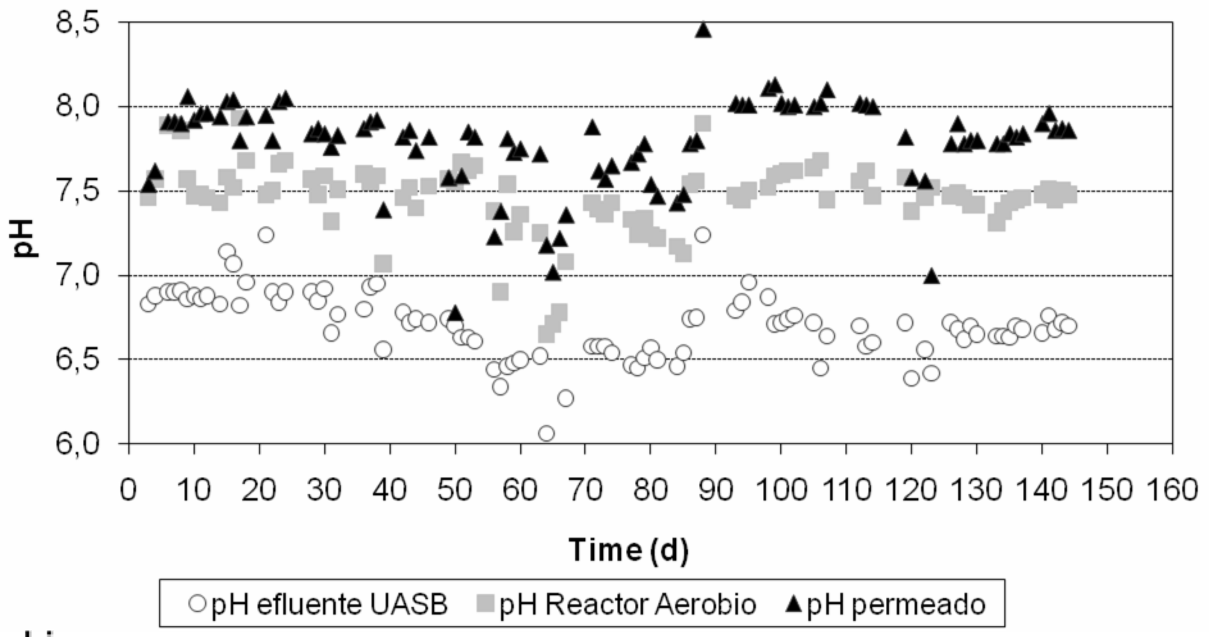


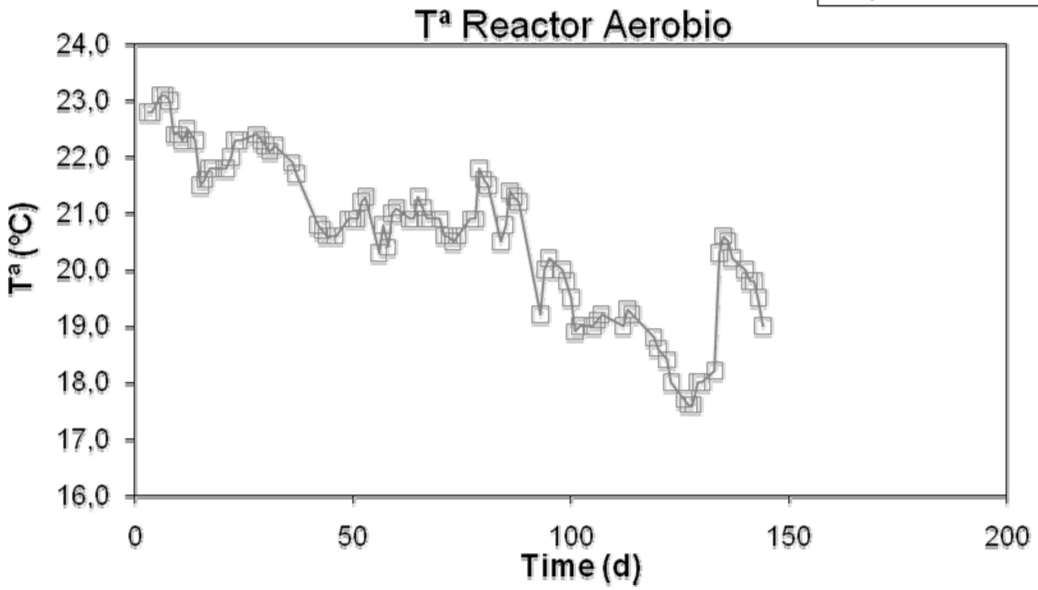


Phosphorous



Temperature, pH





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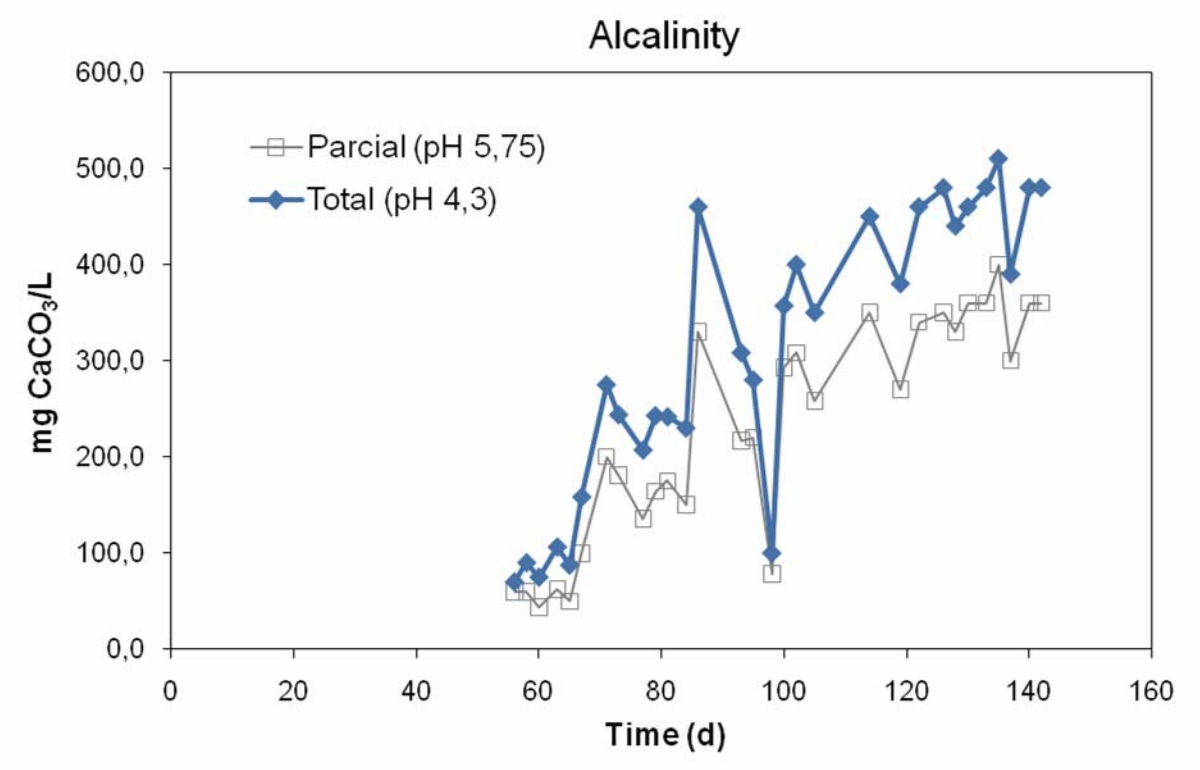
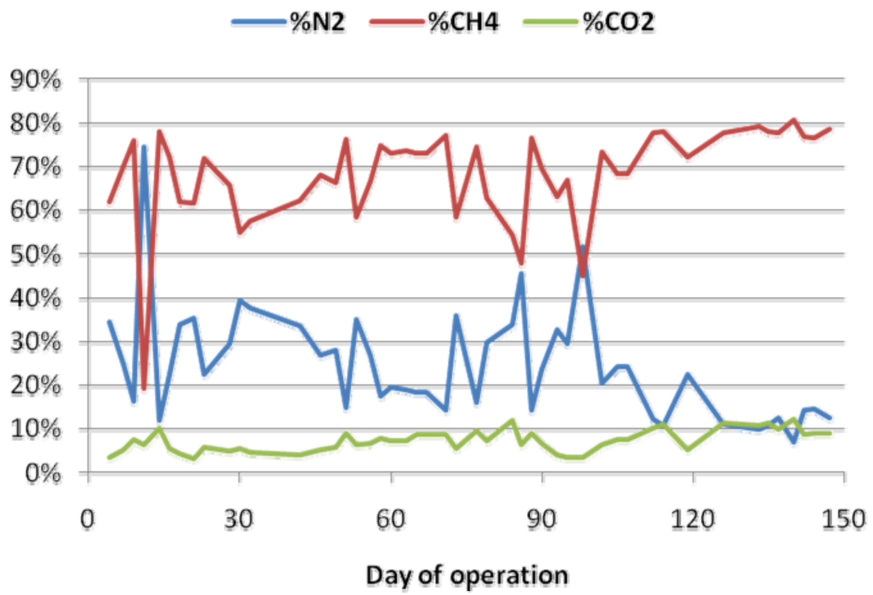
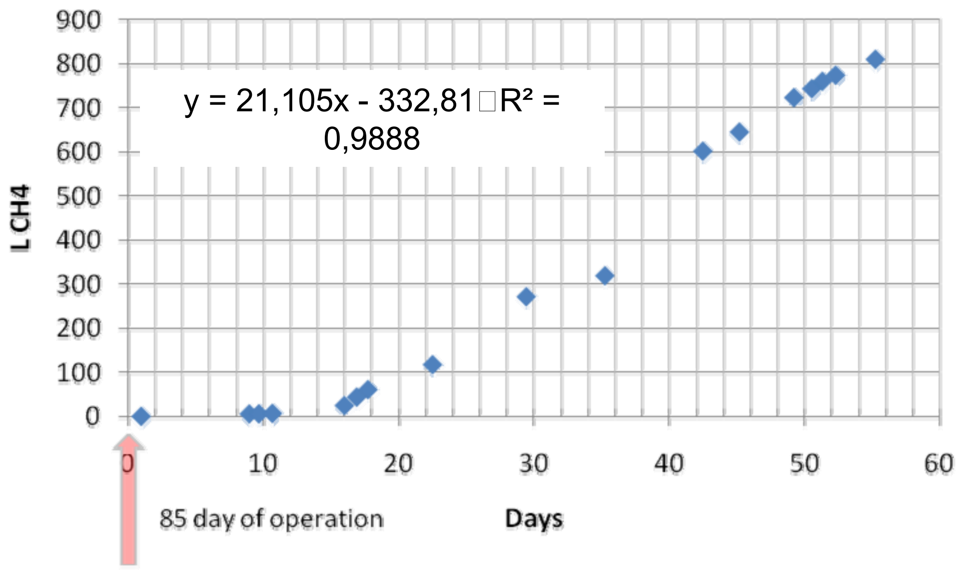
Alkalinity

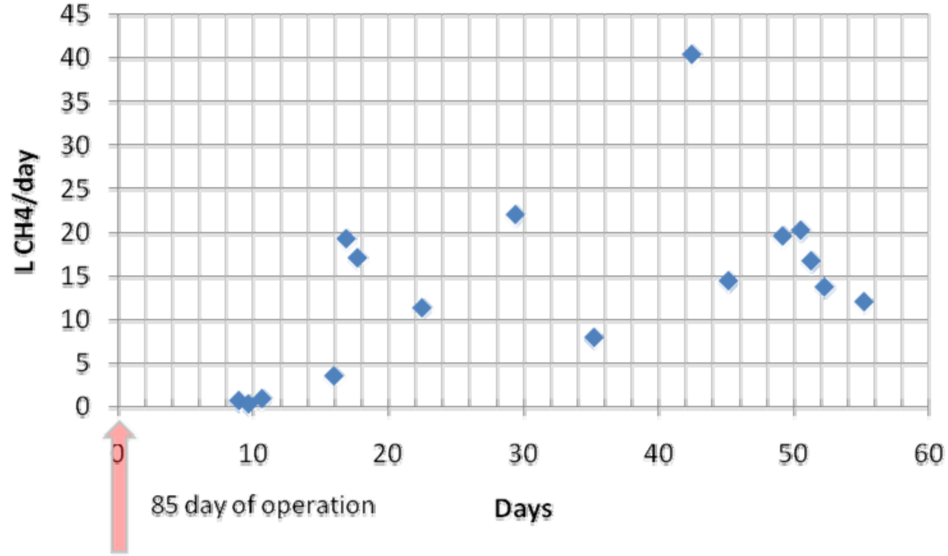

Alcalinity
mg $CaCO_3$/L
600,0
500,0
400,0
300,0
200,0
100,0
0,0
Parcial (pH 5,75)
Total (pH 4,3)
0
20
40
60
80
100
120
140
160
Time (d)

Biogas

Biogas production

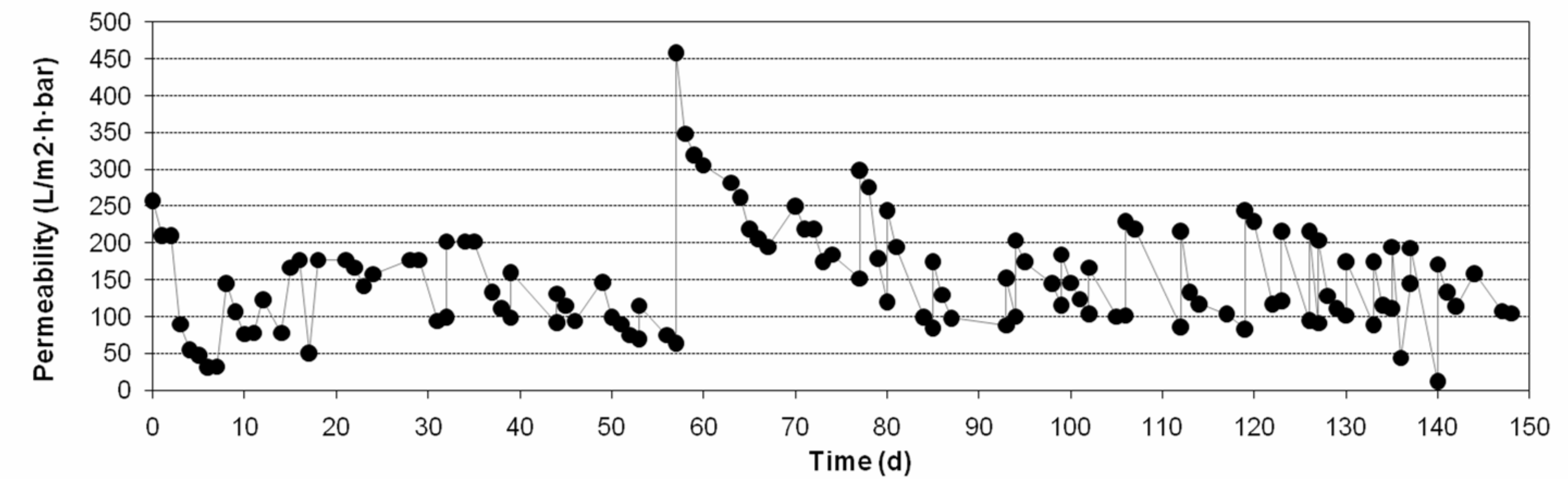


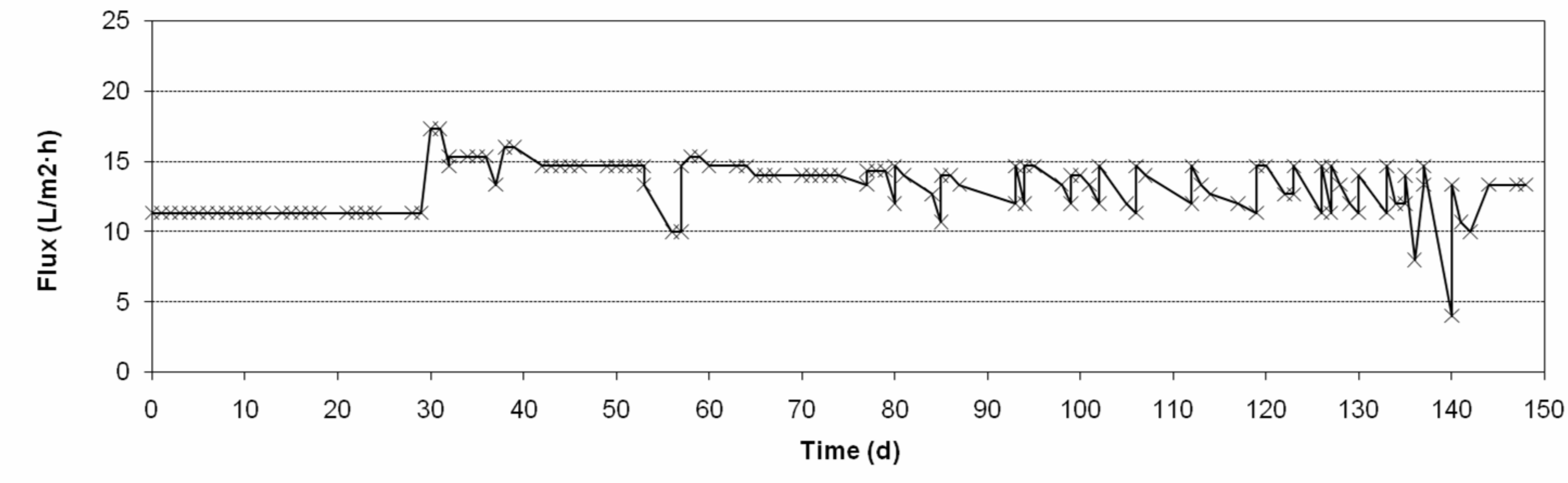




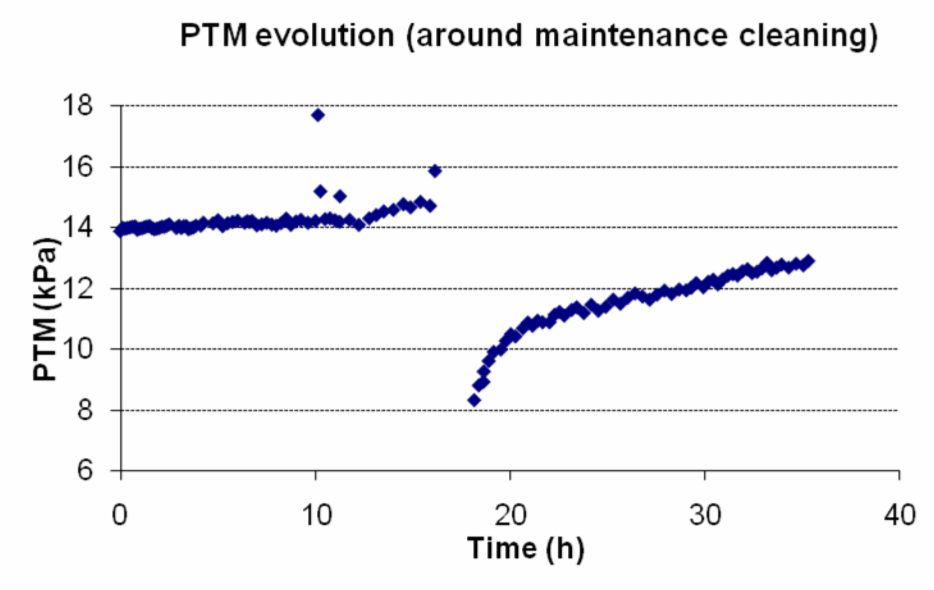
Membrane

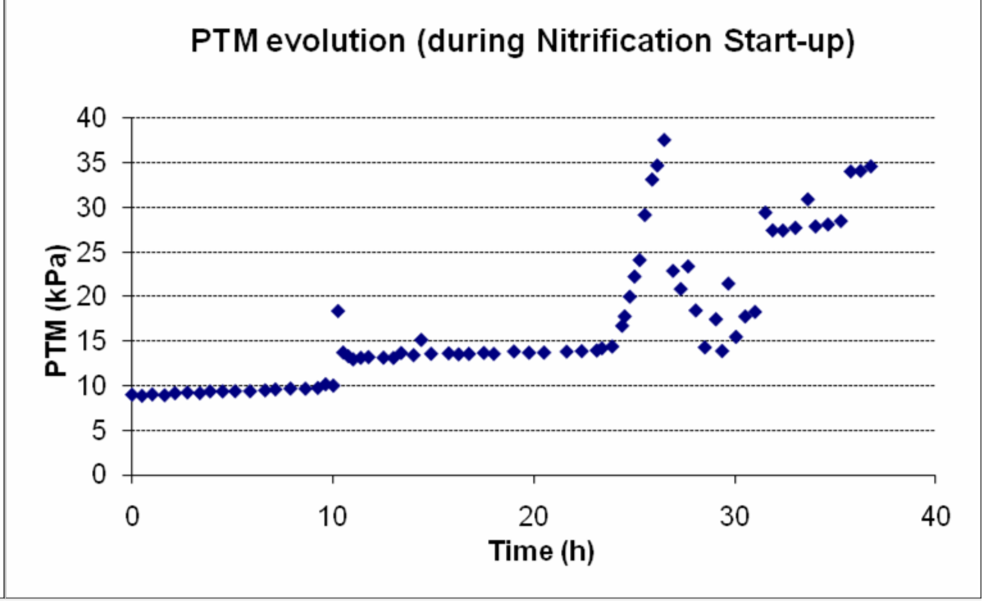
Permeability and Flux

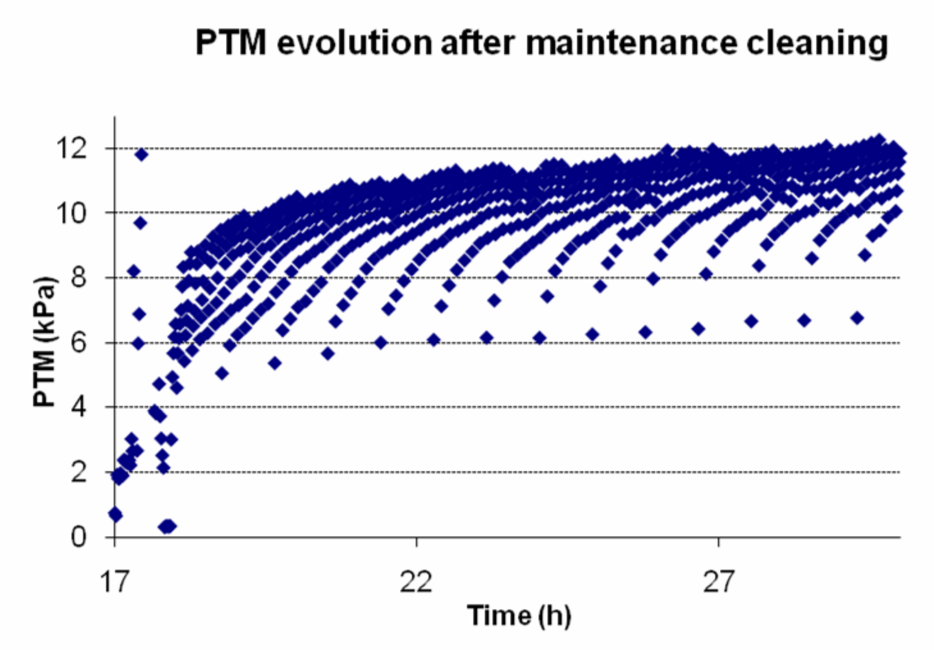


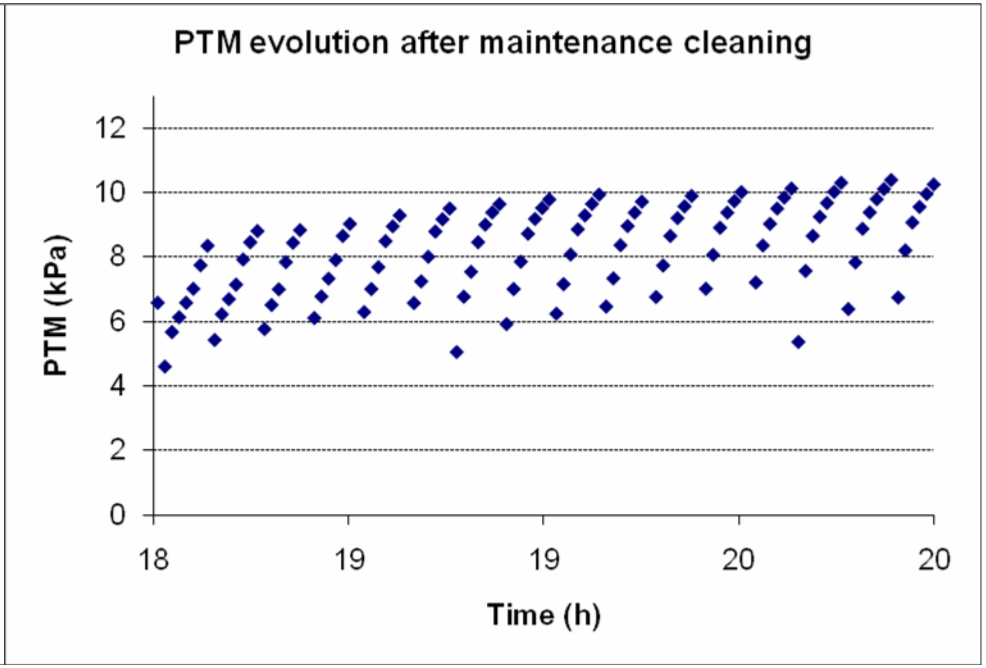


Transmembrane Pressure (TMP)

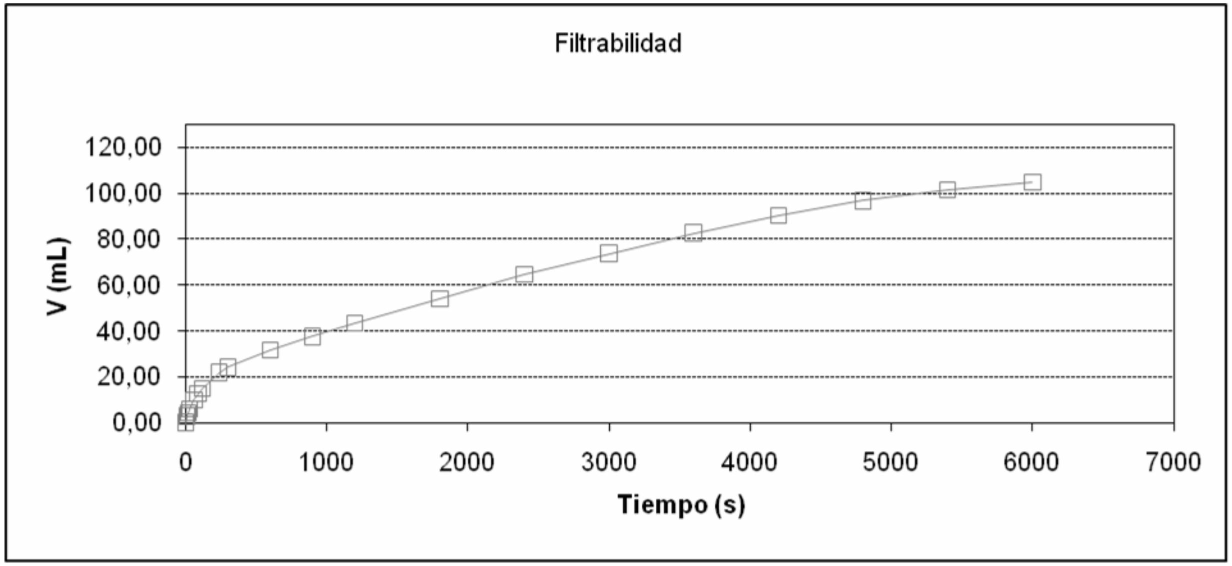


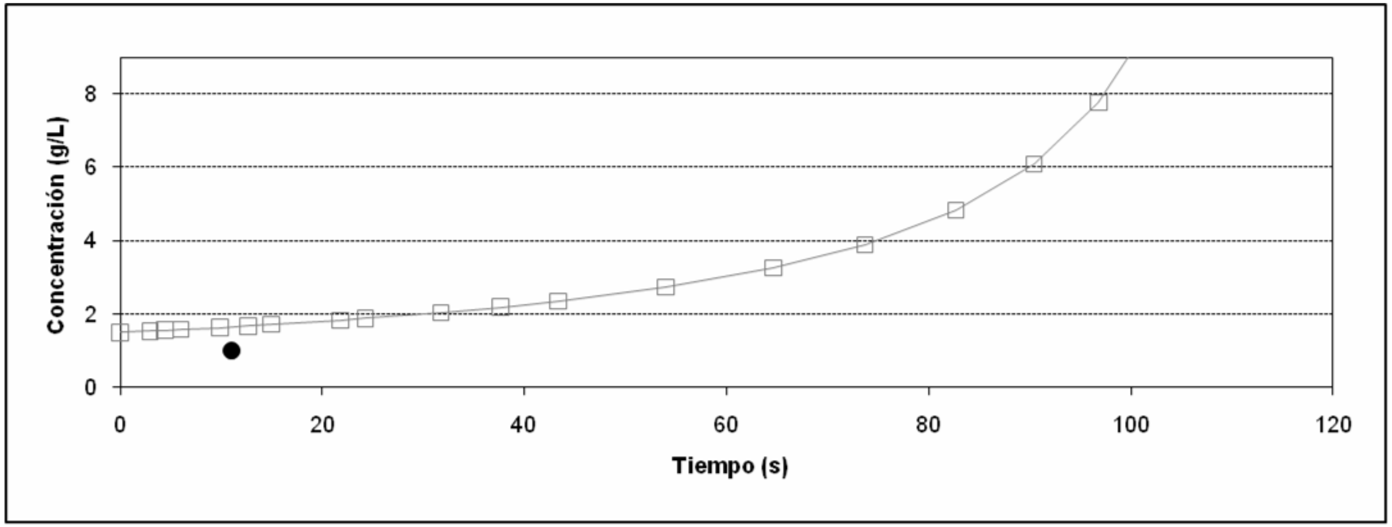




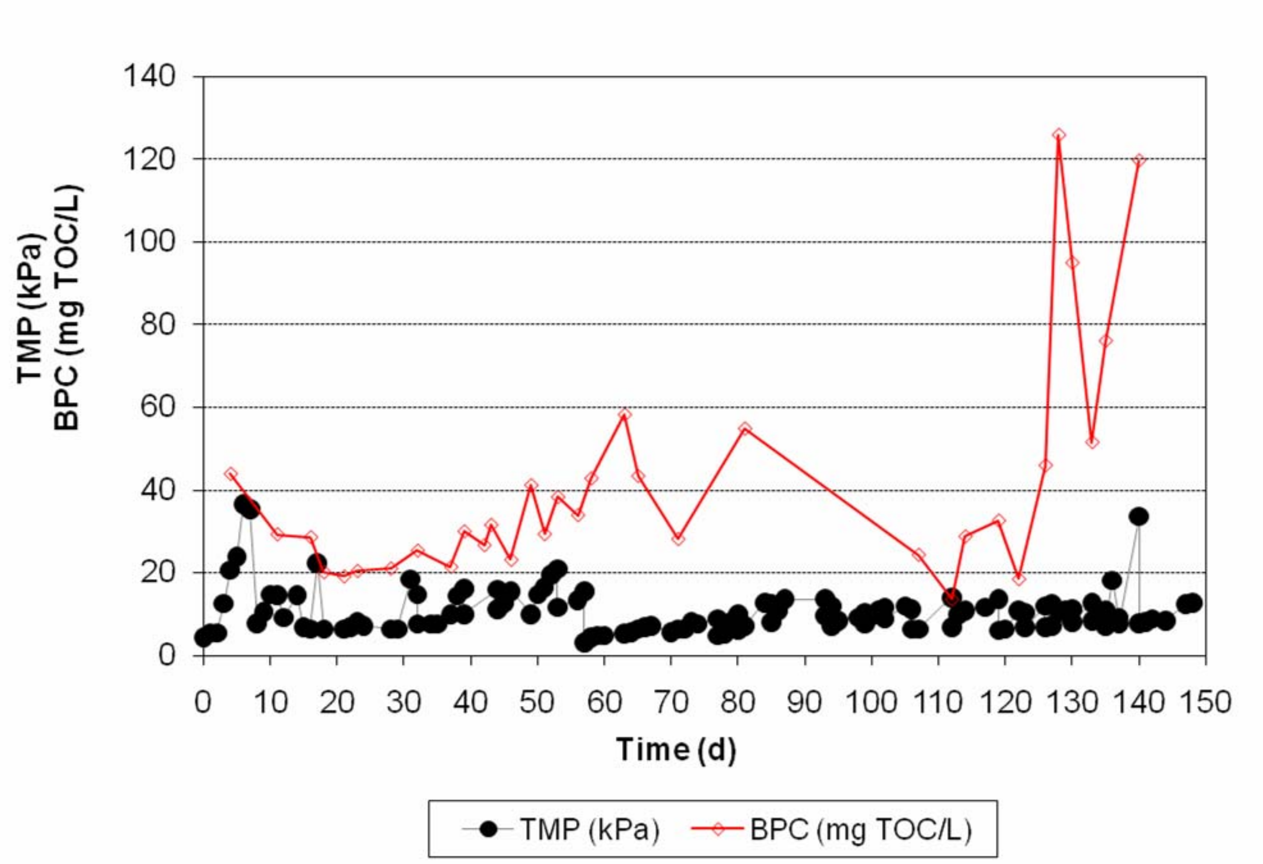


Filtrability

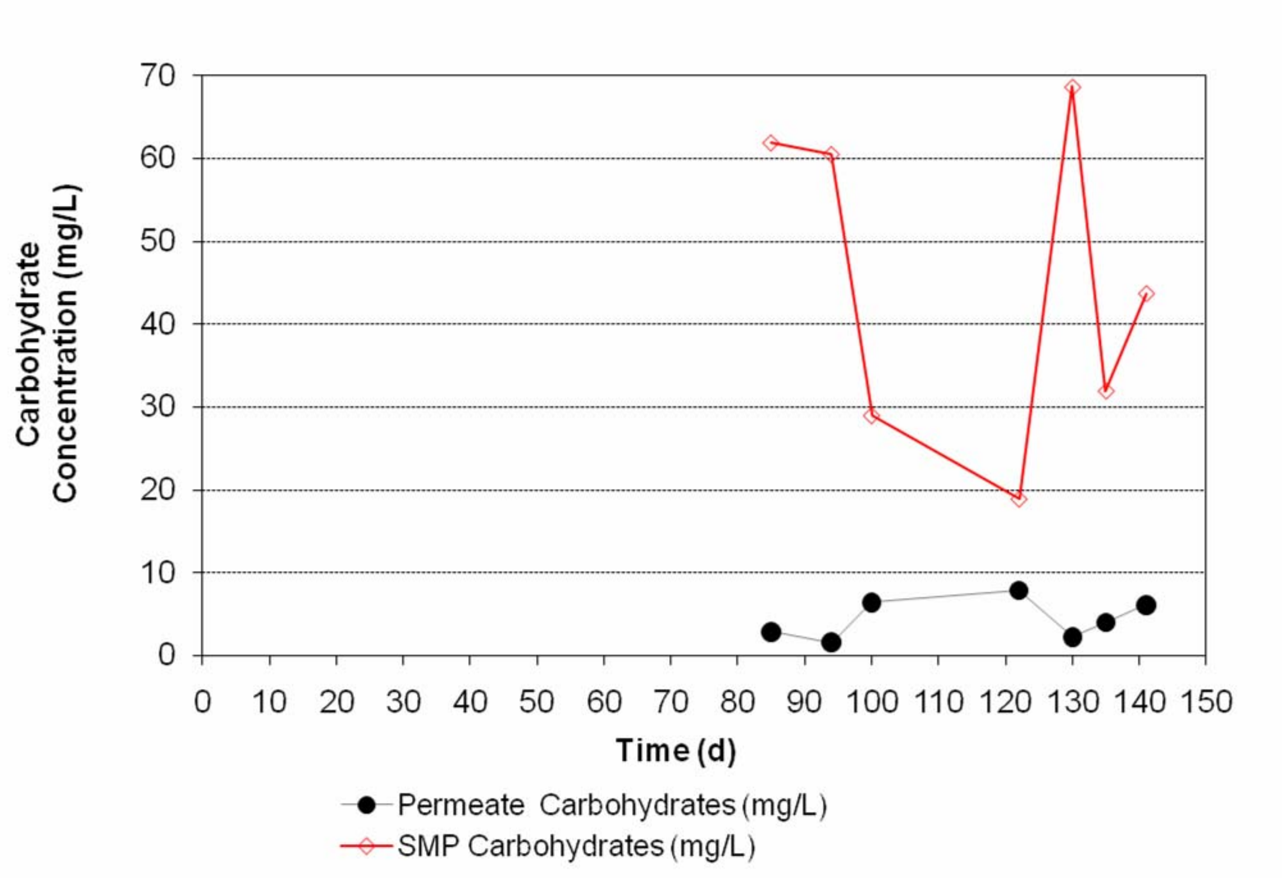




Transmembrane pressure (TMP) and Bacterial Polymeric Clusters (BPC)

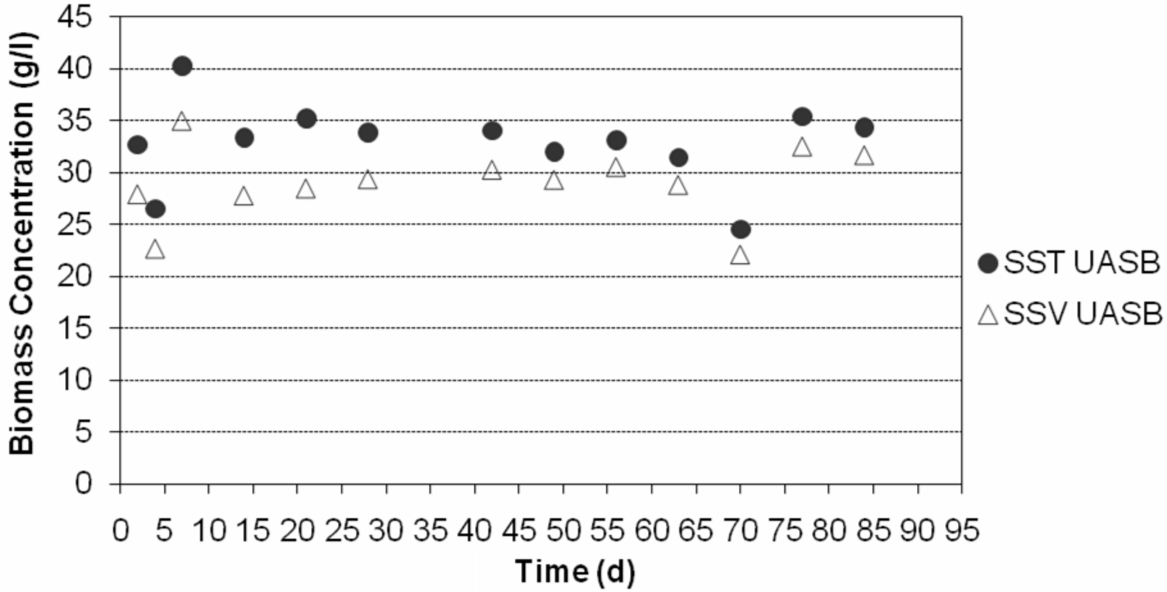


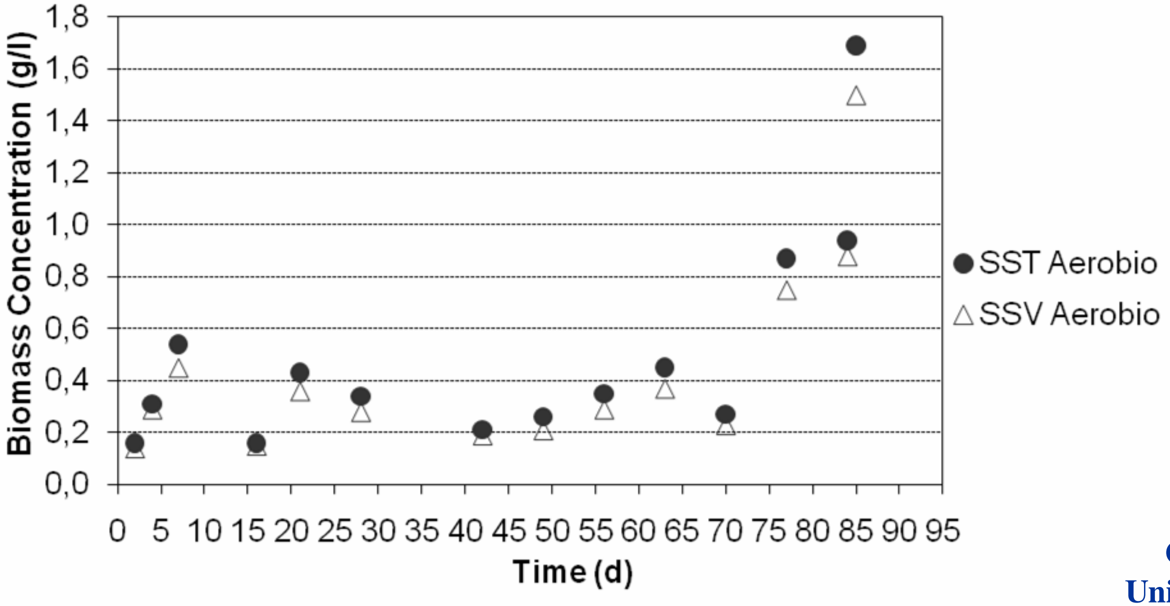
Carbohydrates



Biomass

Biomass development





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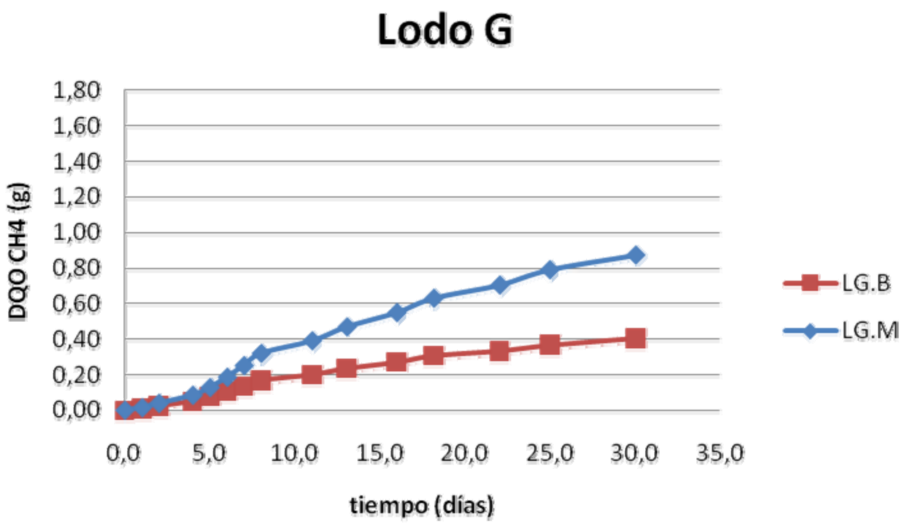
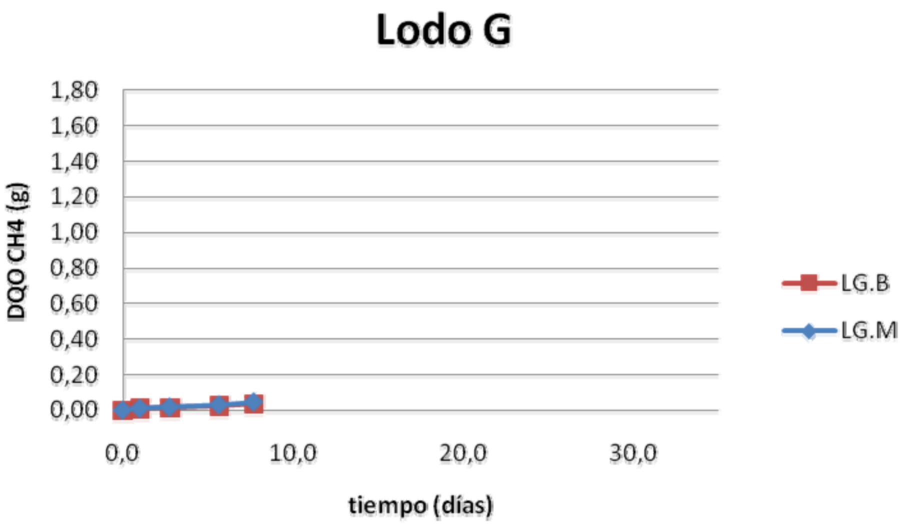
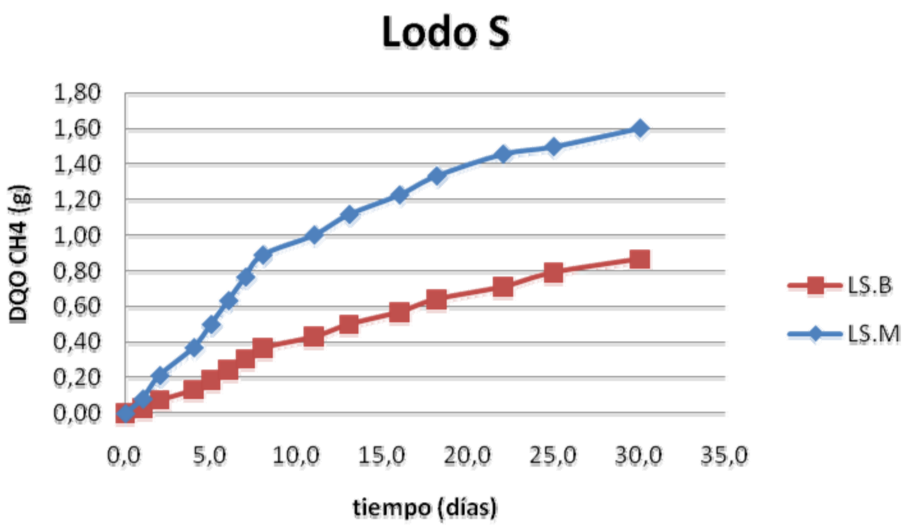
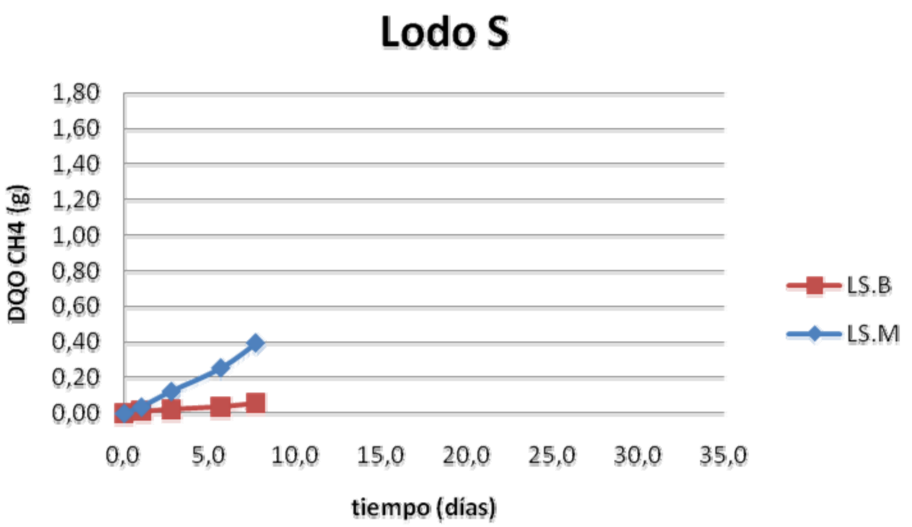
Specific methanogenic activity



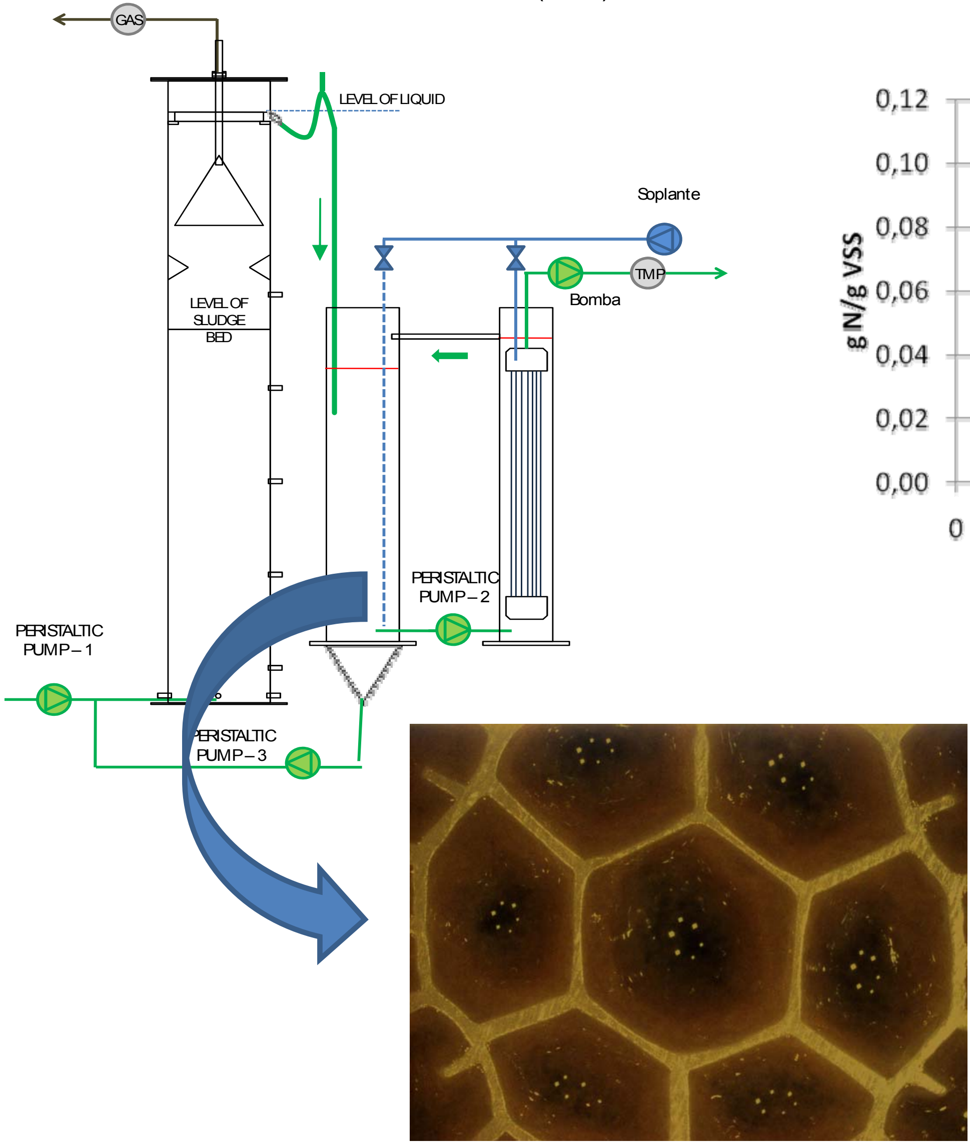


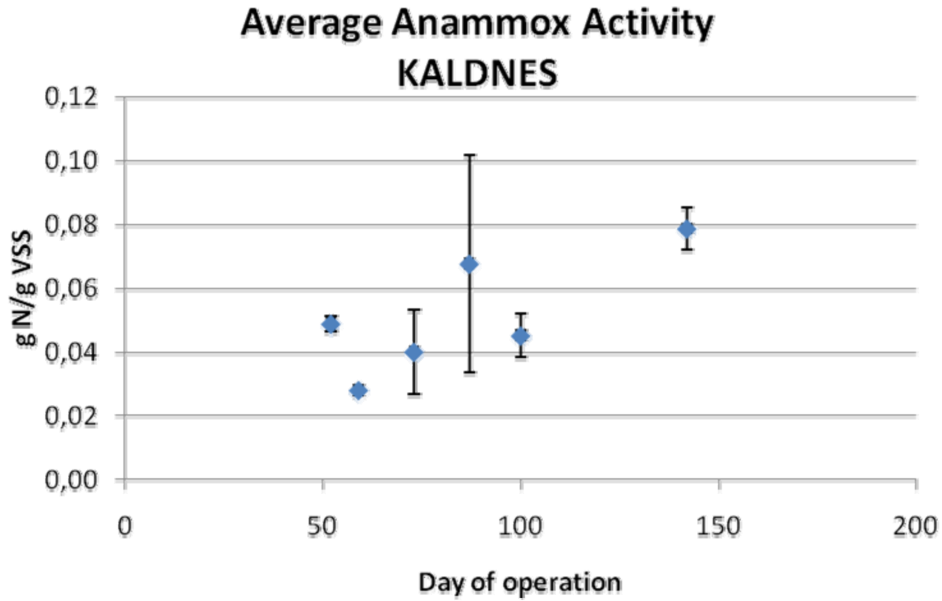




Anammox activity

Details of the HYBRID reactor (176 L)





The reference: ***0,5 gN/gVSS***
(¨Mother¨ reactor for Anammox bacteria cultivation)

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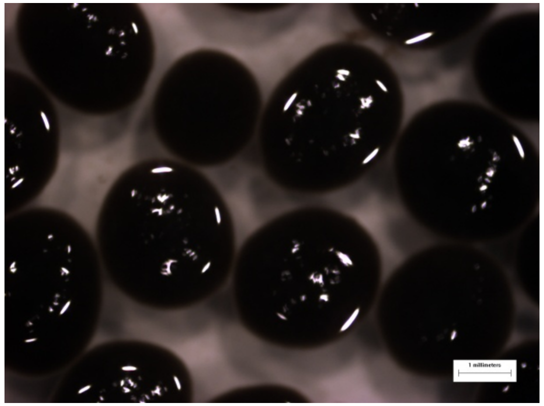
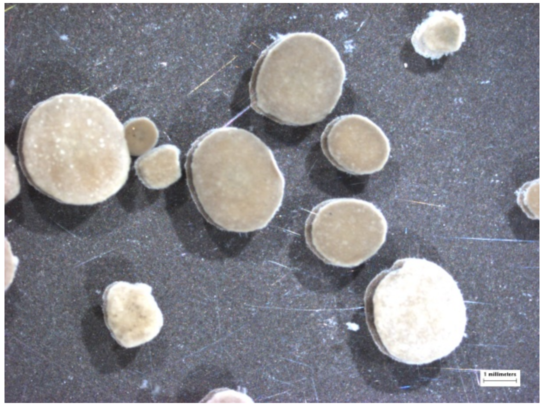
Methanogenic Biomass development



SAMPLING PORT 1

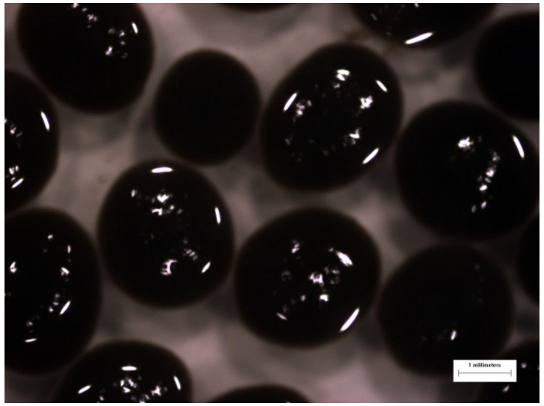
SAMPLING PORT 3



SAMPLING PORT 5

Methanogenic Biomass development

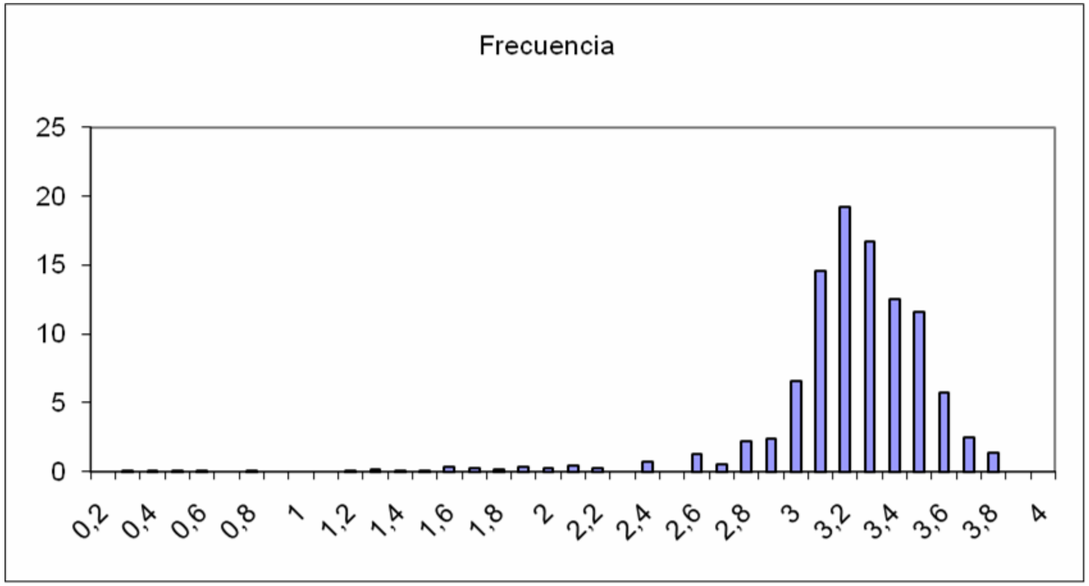
3rd February 2010

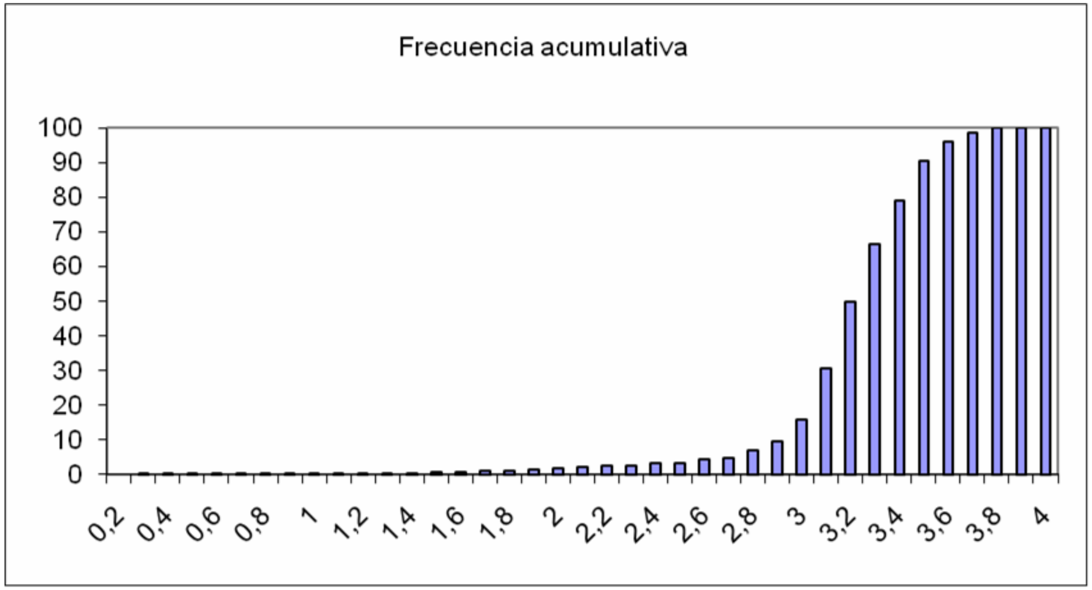


SAMPLING PORT 1

SAMPLING PORT 3

Size distribution Methanogenic Granules – Port 1





Volumen total	Volumen medio
2140,33	13,99
radio medio	**diametro medio**
1,49	2,99

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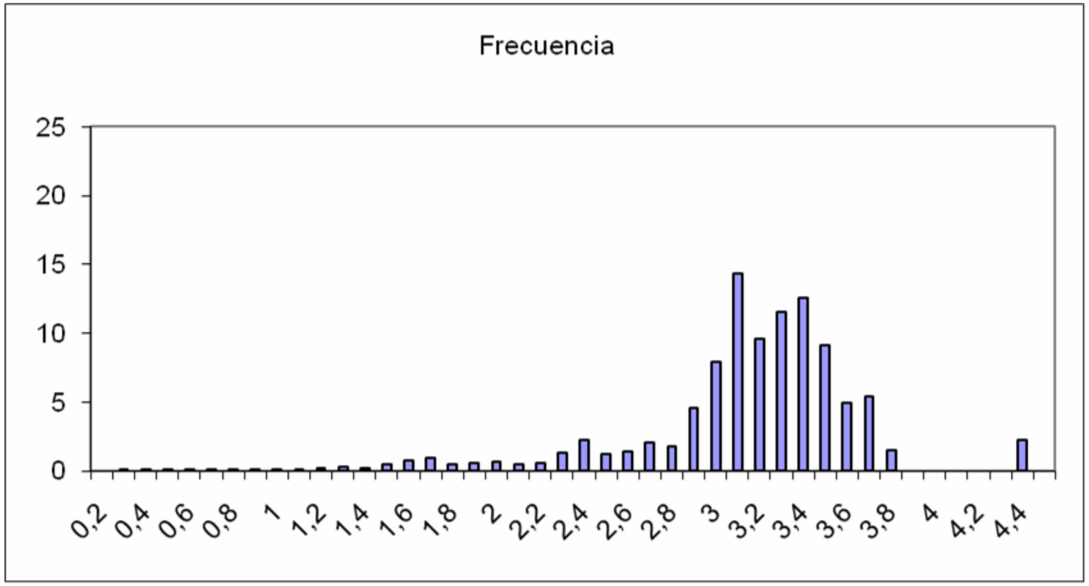
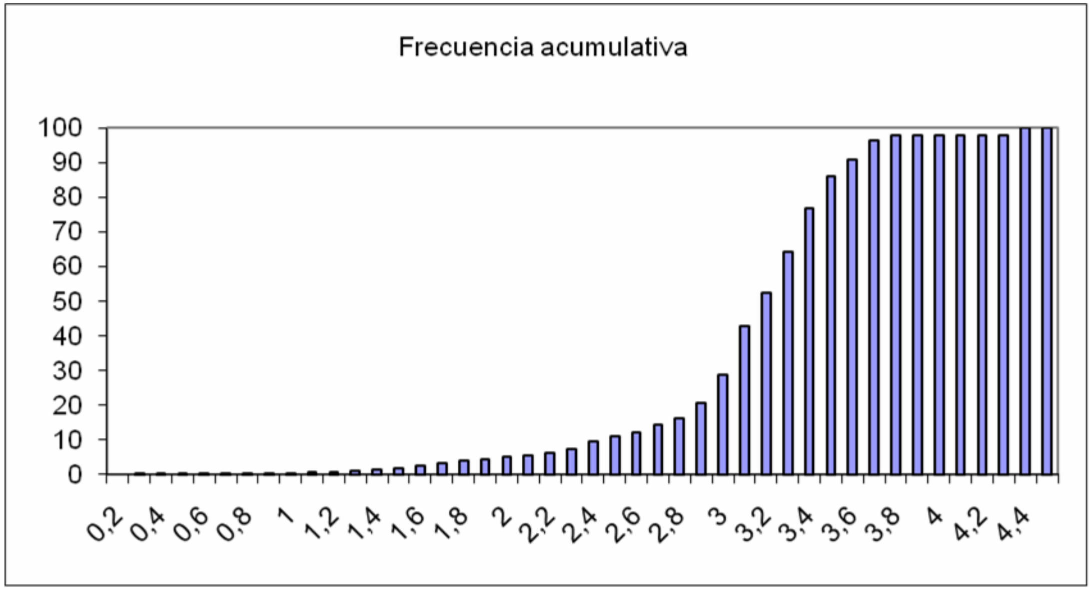
Size distribution Methanogenic Granules – Port 3





Volumen total	Volumen medio
1958,87	9,11
radio medio	**diametro medio**
1,30	2,59

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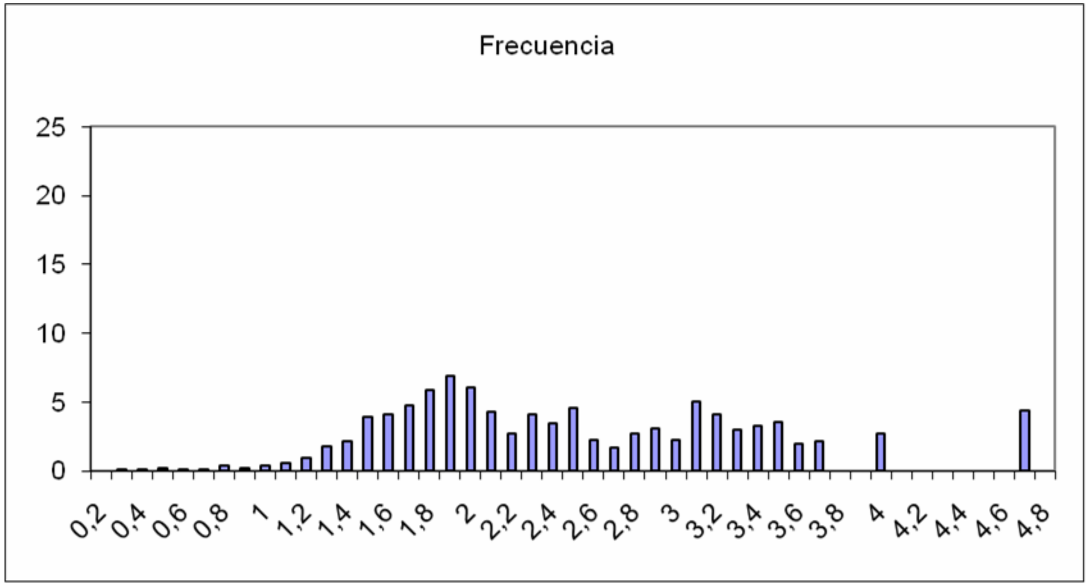
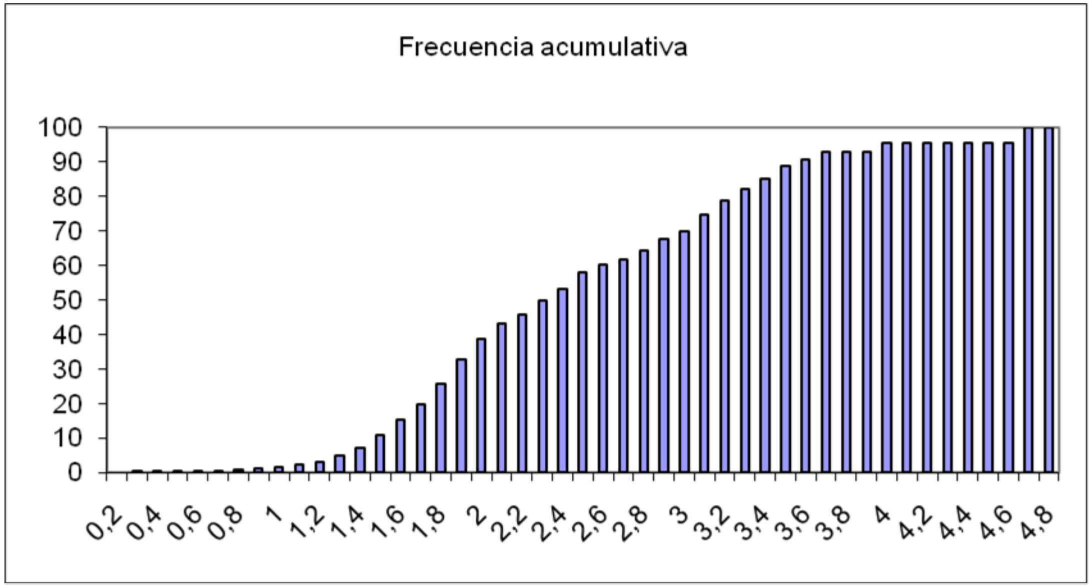
Size distribution Methanogenic Granules – Port 5





Volumen total	**Volumen medio**
1247,19	3,21
radio medio	**diametro medio**
0,92	1,83

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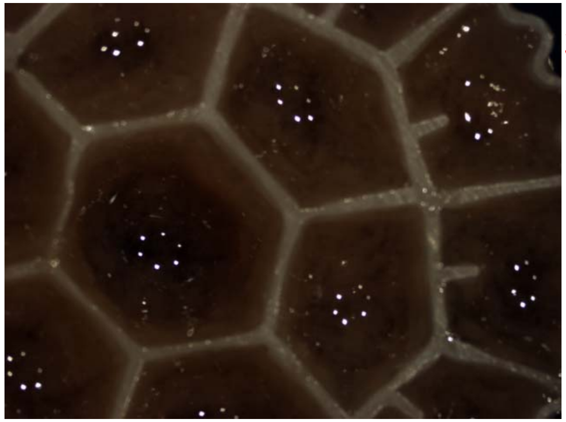
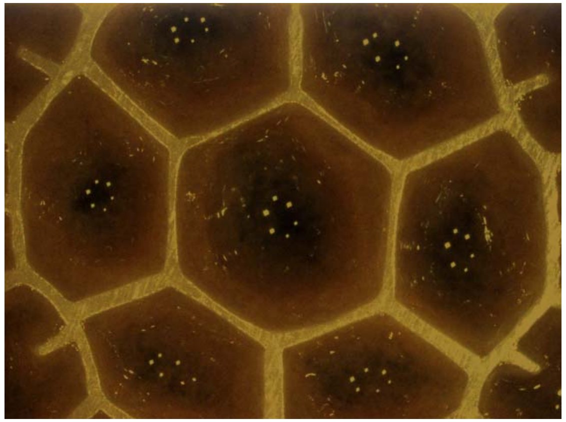
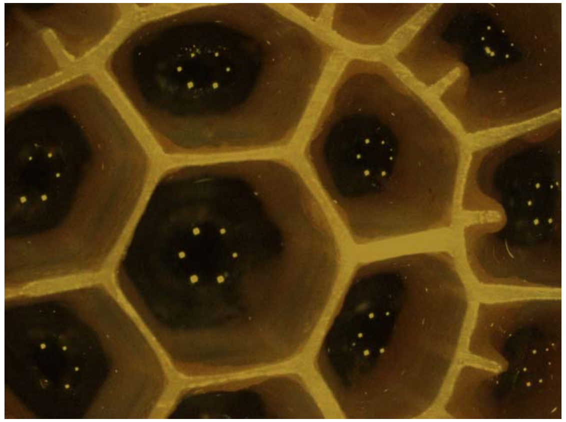
Aerobic Biofilm development



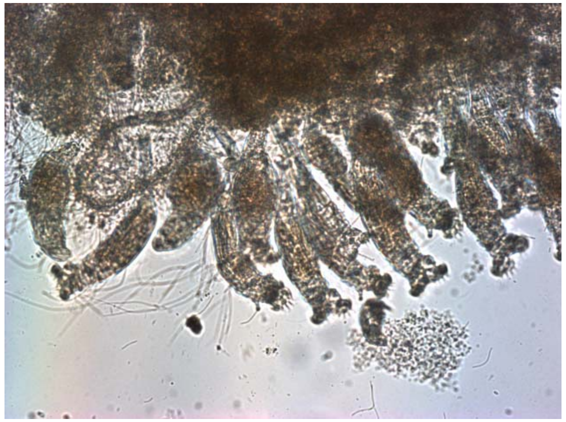
30-10-2009

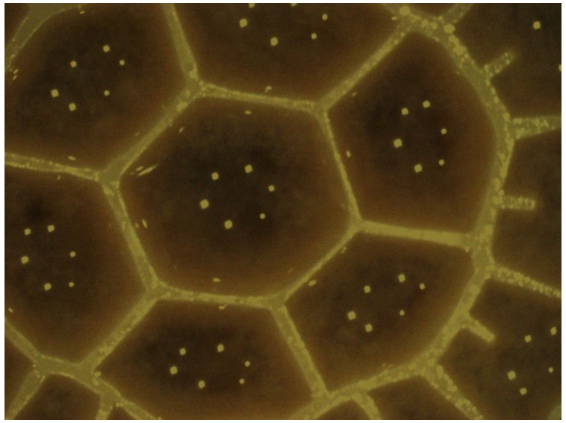


15-12-2009



08-01-2009





26-01-2009

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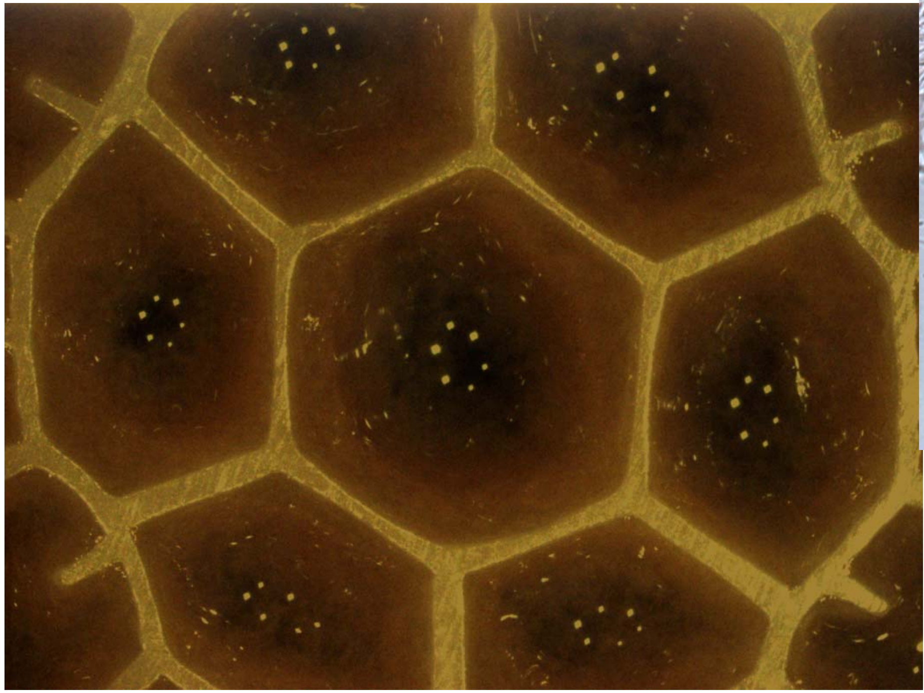
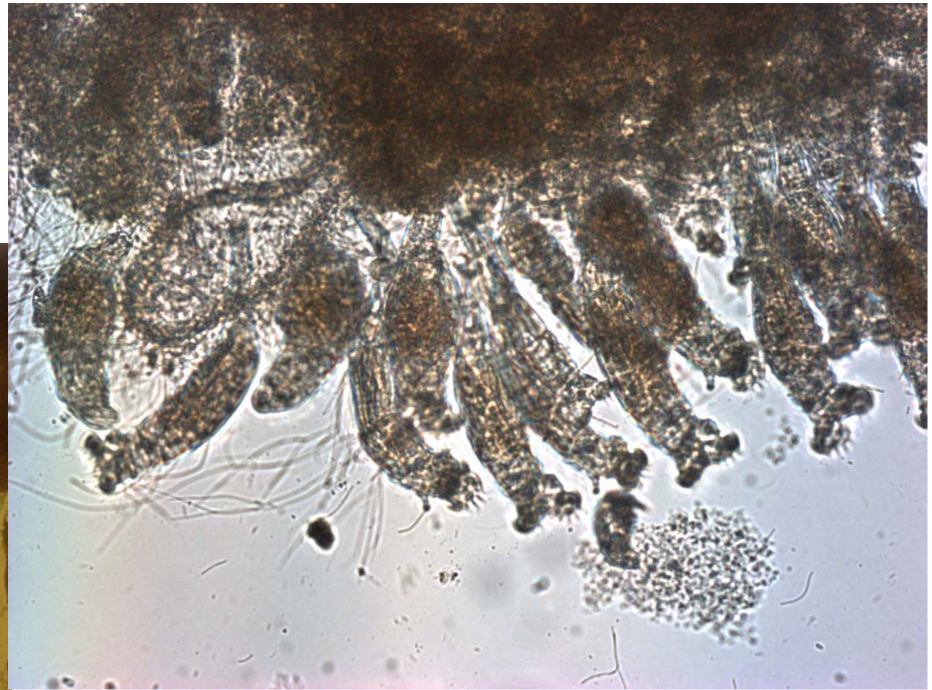
Photos of the aerobic biofilm





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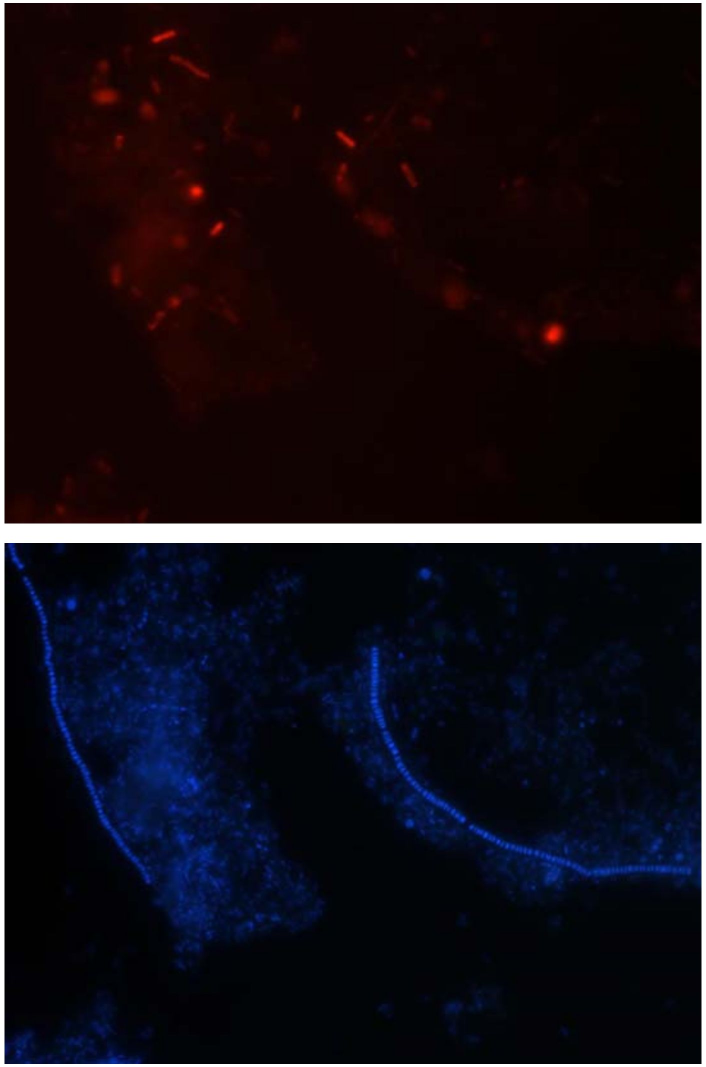
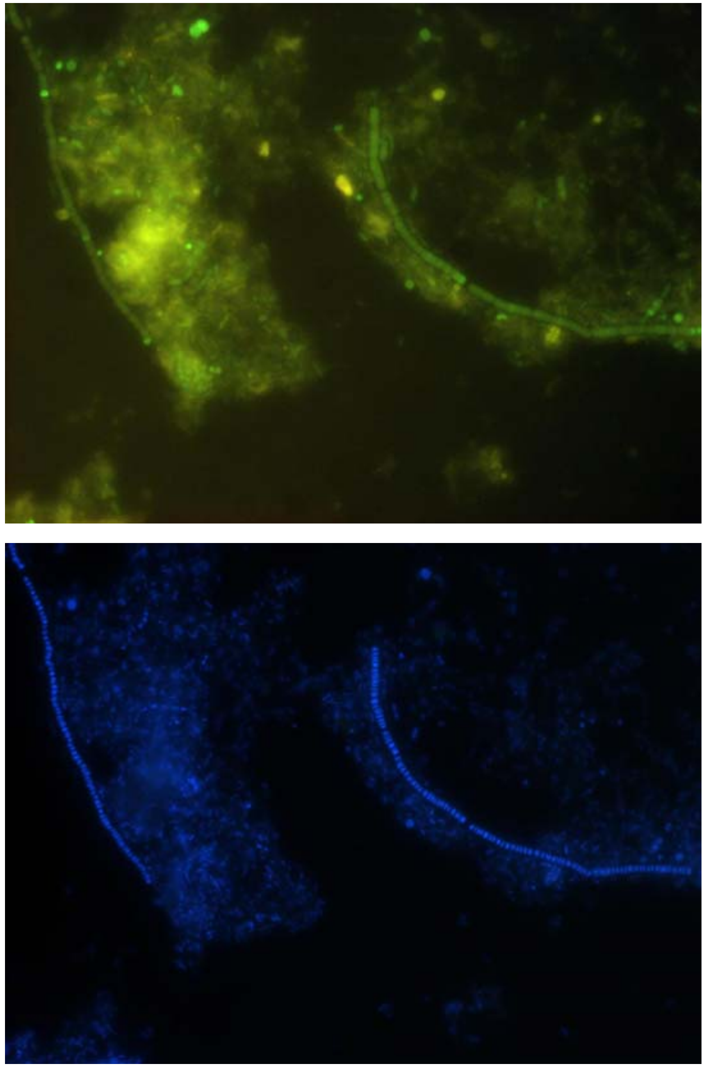
FISH analysis: Methanogenic Sludge

Sampling port 1 Date: 08-12-2009

33 ARC915 cy3 *Archaea* (x100)



I EUB3381 Fluos *Bacteria domain* (x100)



Conclusions

Biology

- COD removal between 50-80 % in the methanogenic stage.
- Remaining biodegradable COD removed in the aerobic stage (biofilms)
- COD concentration lower than 30 mg/L at the effluent (permeate)
- Negligible BOD concentration at the effluent
- Anammox biomass development detected

Membrane

- Permeabilities in between 100 and 250 $L/m^2h \cdot bar$
- Membrane easily recovered using physical cleaning (water flushing)
- Membrane fouling tendency still worst than in aerobic MBR

Regional government: Xunta de Galicia

Project 09MDS009265PR

THANK YOU !