Biorefinery pilot plant for resources recovery from agricultural waste

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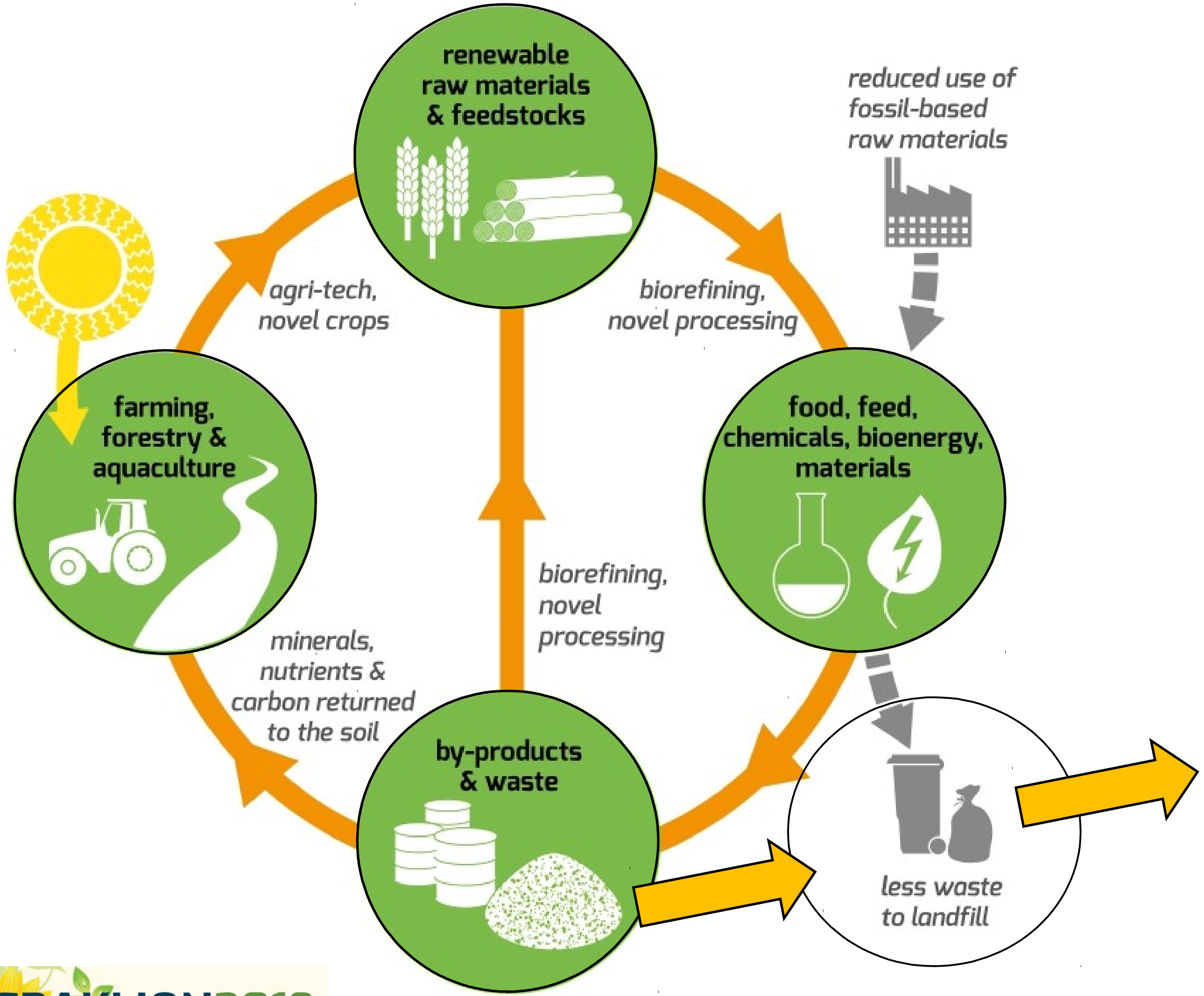
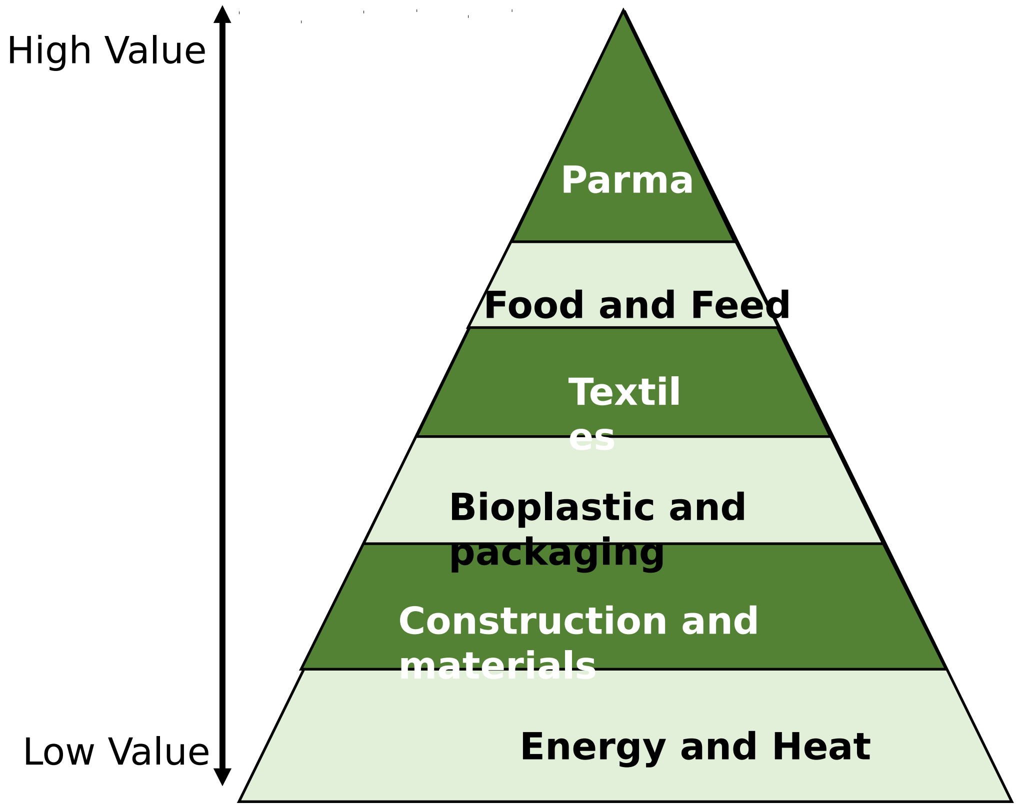
The Bioeconomy Concept

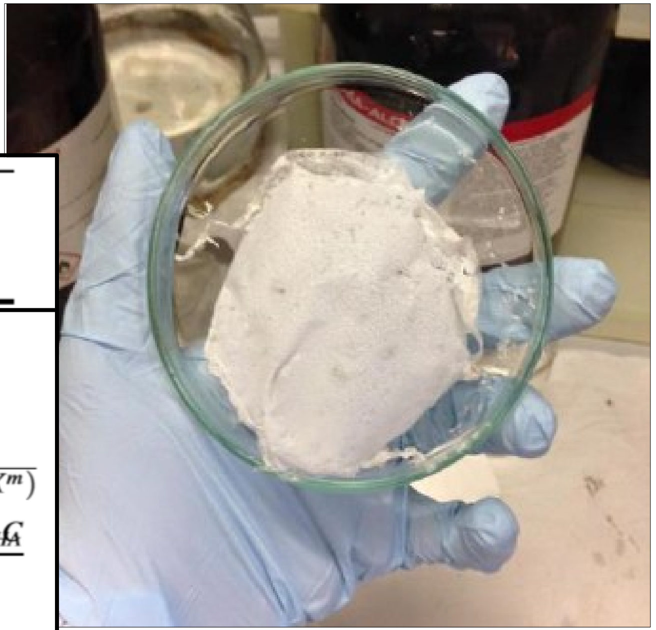




The Bioeconomy Concept

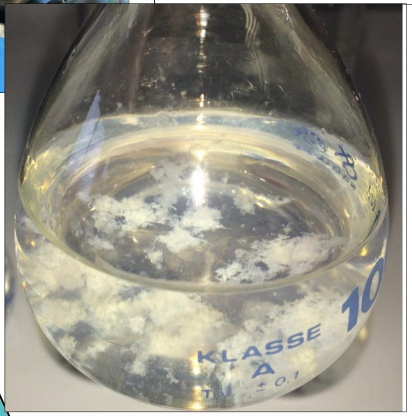
Anaerobic digestion without biogas?

Robbert Kleerebezem · Bart Joosse ·
Rene Rozendal · Mark C. M. Van Loosdrecht



Process	Anaerobic digestion	PHA production
Price end-product	$€_{CH4} = 0.4$ €/kg	$€_{PHA} = 2.0$ €/kg
Revenue calculation	$Rev = \frac{Q \cdot VFA_i \cdot Y_{CH4/\overline{VFA}} \cdot C}{COD_{CH4}}$	$\vartheta = \frac{f_{PHA} \cdot PHA^m}{PHA^m - f_{PHA} \cdot (PHA^m - X^m)}$ $Rev = \frac{Q \cdot VFA_i \cdot \vartheta \cdot Y_{PHA/\overline{VFA}} \cdot C}{COD_{CH4}}$
Revenue	3.6 k€/day	20.2 k€/day

The Death Valley of Innovation



Horizon 2020 Project

GLOPACK

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NoAW

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TRL 9

TRL 8

TRL 7 – System prototype demonstration in operational environment

TRL 6

TRL 5 – Technology validated in relevant environment (industrially relevant environment in the case of key enabling technologies)

TRL 4

TRL 3

TRL 2

TRL 1

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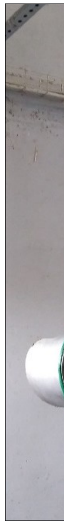
Bio-Refinery Pilot plant

Stage 1
Feeding of the Agro-waste

Stage 2
Grinding and Pumping Station

Stage 3
Fermented Liquor Production

Stage 4
Screw-press



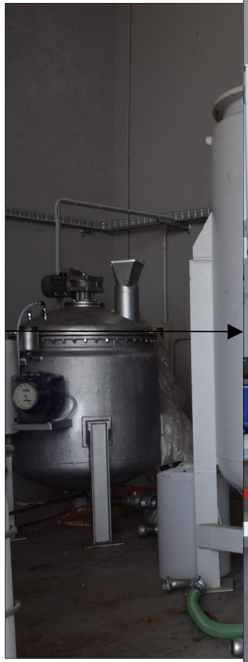
Stage 5
Screening of the liquid

Liquid Fraction

Solid fraction
For biogas and
digestate prodction

Stage 5
Liquid fraction

Stage 6
Selection SBR



Stage 7
Accumulation SBR

Stage 8
Thickening of the Biomass

Feedstock composition

Parameter	Unit	Minimum				Maximum			
		Liquid Manure	Water	Grass Residues	Mixture	Liquid Manure	Water	Grass Residues	Mixture
% of feed	% (W/W)	53	30	17	100	60	23	17	100
TS	KgTS/tTQ	80	-	350	71	95	-	400	74
TVS	KgTVS/tTQ	70	-	313	63	73	-	360	64
COD	KgO_2/tTQ	44	-	312	53	54,256	-	358,25	72
NH_3	KgN/tTQ	1	-	0,1	0,4	1,3	-	0,1	0,6
TKN	KgN/tTQ	1,9	-	4,72	1,3	3,56	-	5,956	2,4
TP	KgP/tTQ	0,3	-	1	0,2	0,689	-	2,3	0,6

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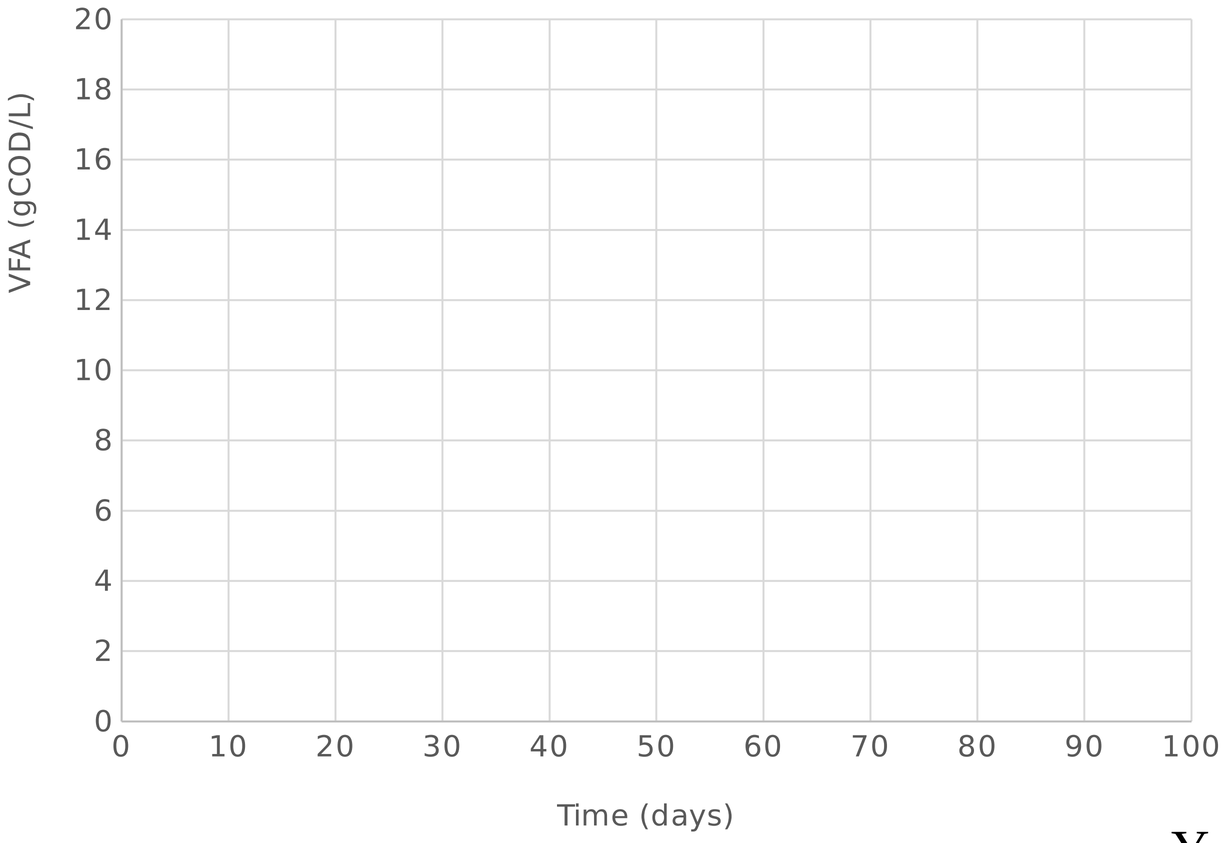
Long term VFAs production

Acidogenic fermentation

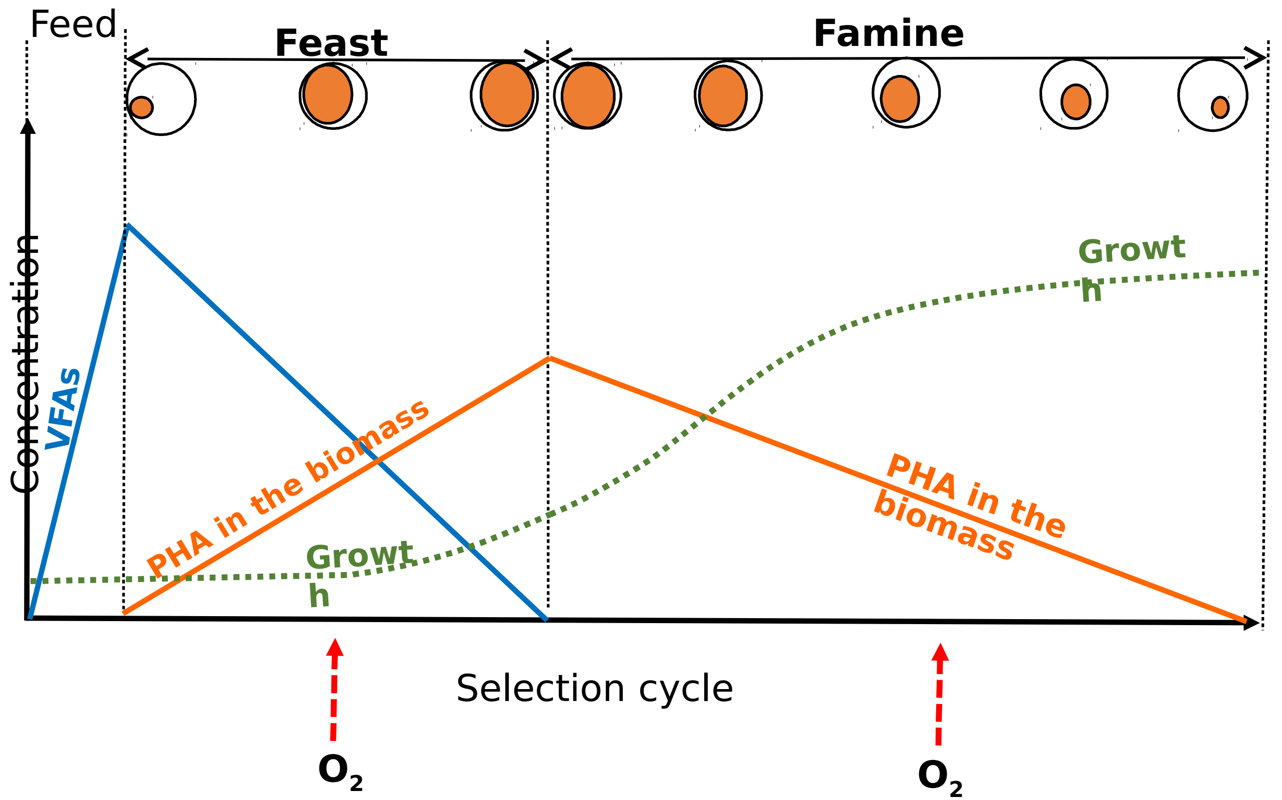


HRT = 4 days
Temperature = 37°C

Volatile Fatty Acids	Unit	Value
Acetic acid	gCOD/L	7,3
Propionic acid	gCOD/L	1,23
Iso-pentenoic acid	gCOD/L	0,23
Iso-butyric acid	gCOD/L	0,04
Butiryic acid	gCOD/L	0,75
Iso-caproic	gCOD/L	0,03
Caproic acid	gCOD/L	0,12

- $Y_{fermentation}$ = 0,13 $gCOD_{VFA}/gTVS_{fed}$
- $Y_{fermentation}$ = 0,15 $gCOD_{VFA}/gTVS_{fed}$ (Cavinato et al., 2017)

Results
The feast & famine condition



- Presence of external carbon substrate: *Feast condition;*
- Absence of carbon source: *Famine condition;*
- Selection of Storing PHAs biomass fraction from microbial mixed culture

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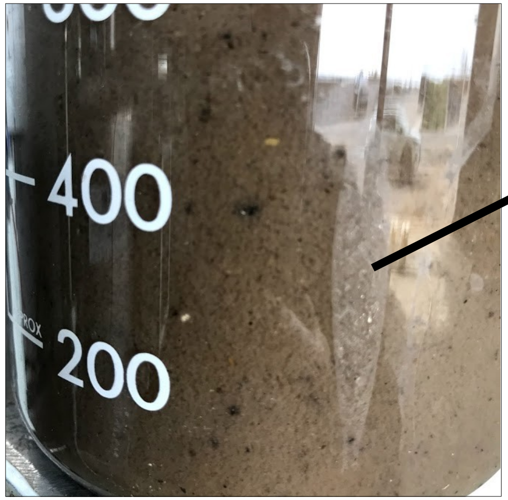
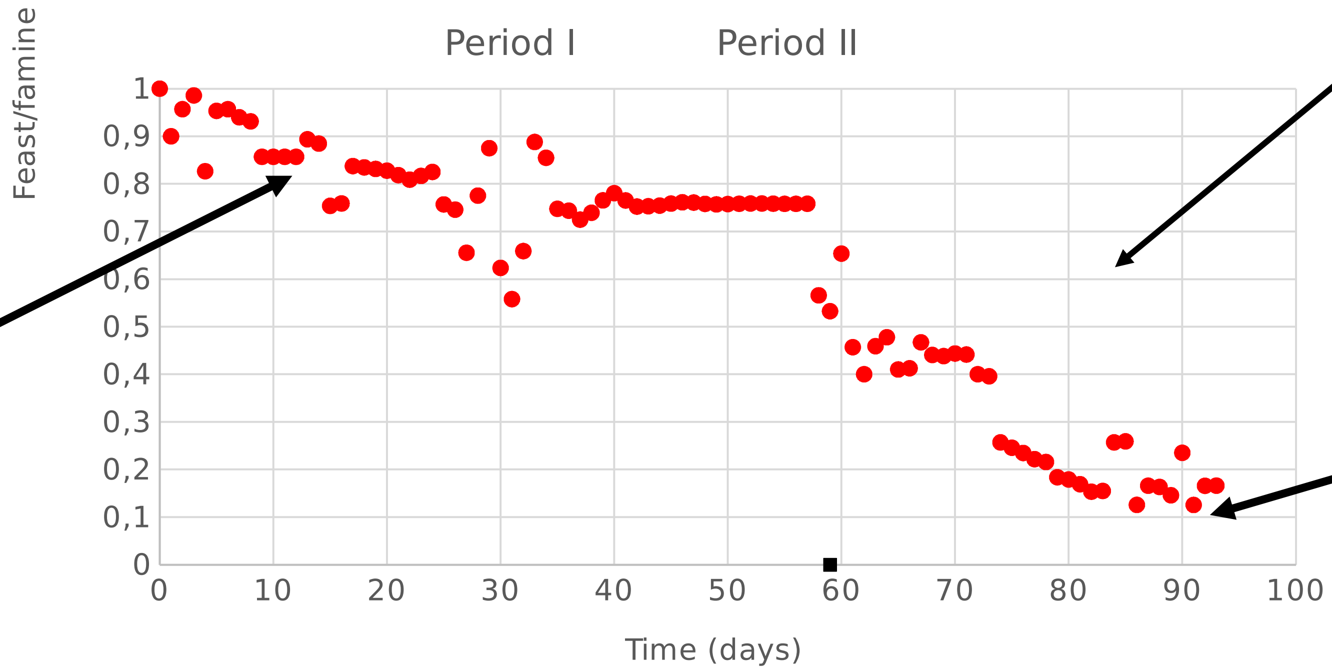
Response of the PHA selection biomass on the Feast to famine ratio

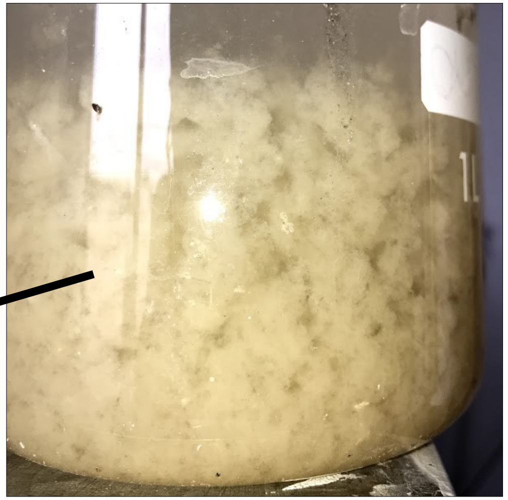
Adjusted F/M ratio in Period II

Inoculum





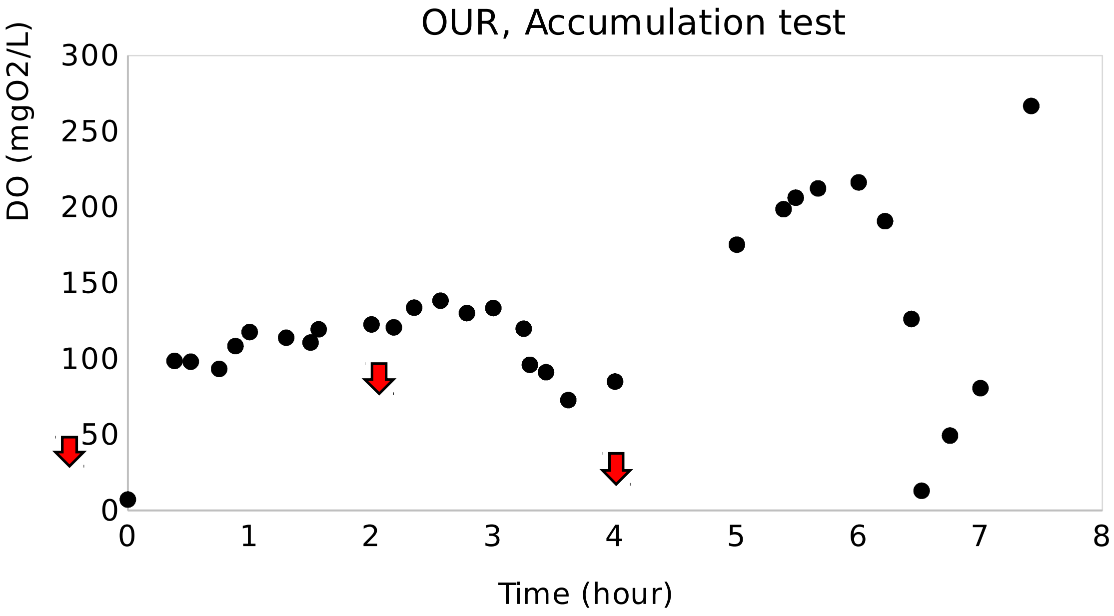
Selected Biomass



- The reduction of the feast to famine ratio (down to 0,13) indicates the occurring of selection of PHA storing biomass;
- In period 2, the VFAs were completely depleted during the cycle.

Results
Accumulation step in SBR II

Accumulation Batch test	Unit	Value
Carbon Source	gCOD/L (C-Spike)	1
N° of C-Spike	-	5
Final volume	m^3	0,9

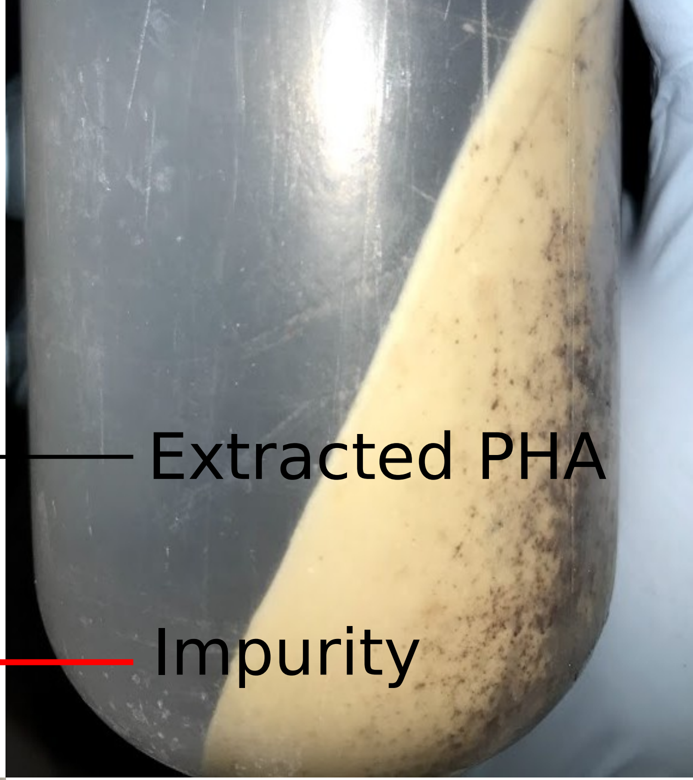


Extraction Step

0,39 Kg NaOH/KgTS (overnight)

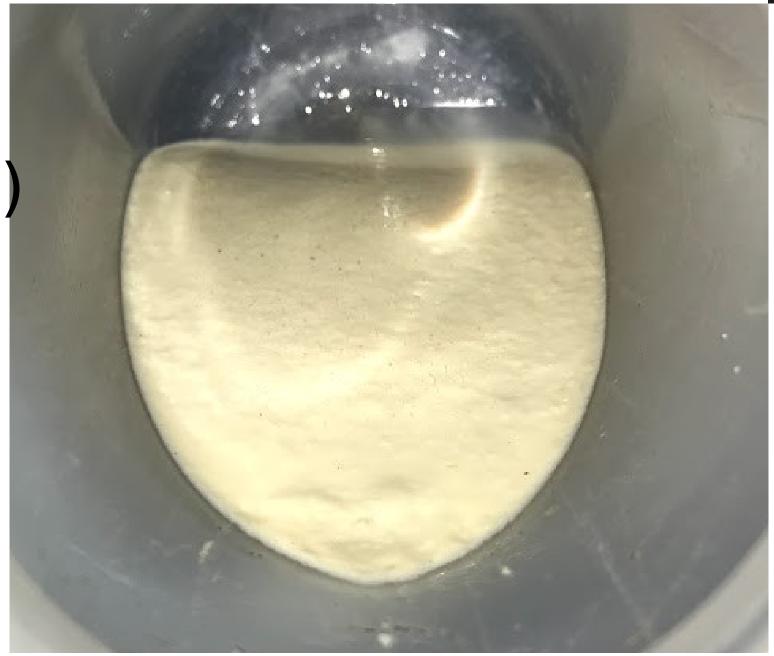
+

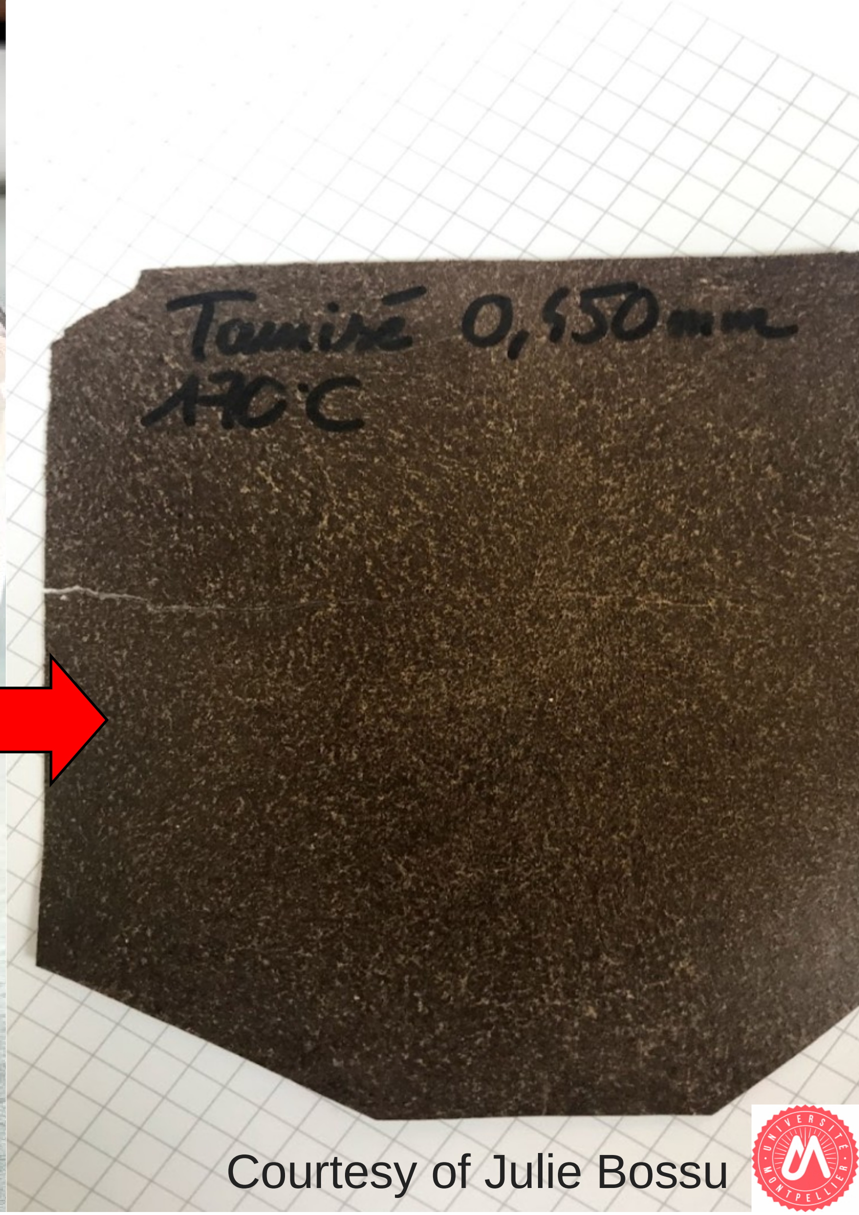
0,245 Kg$C_2H_4O_3$ /KgTS (overnight)



Extracted PHA

Impurity





45°C Overnight

Courtesy of Julie Bossu

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Conclusions

- ✓Biorefinery pilot plant treating agro-waste for PHAs production was implemented in Isola della Scala (Italy);

- ✓The maximal PHA production capacity is around 500 gPHA/day;

- ✓The presence of inerts and fibers contained from the carbon source negatively affected the PHA extraction process;


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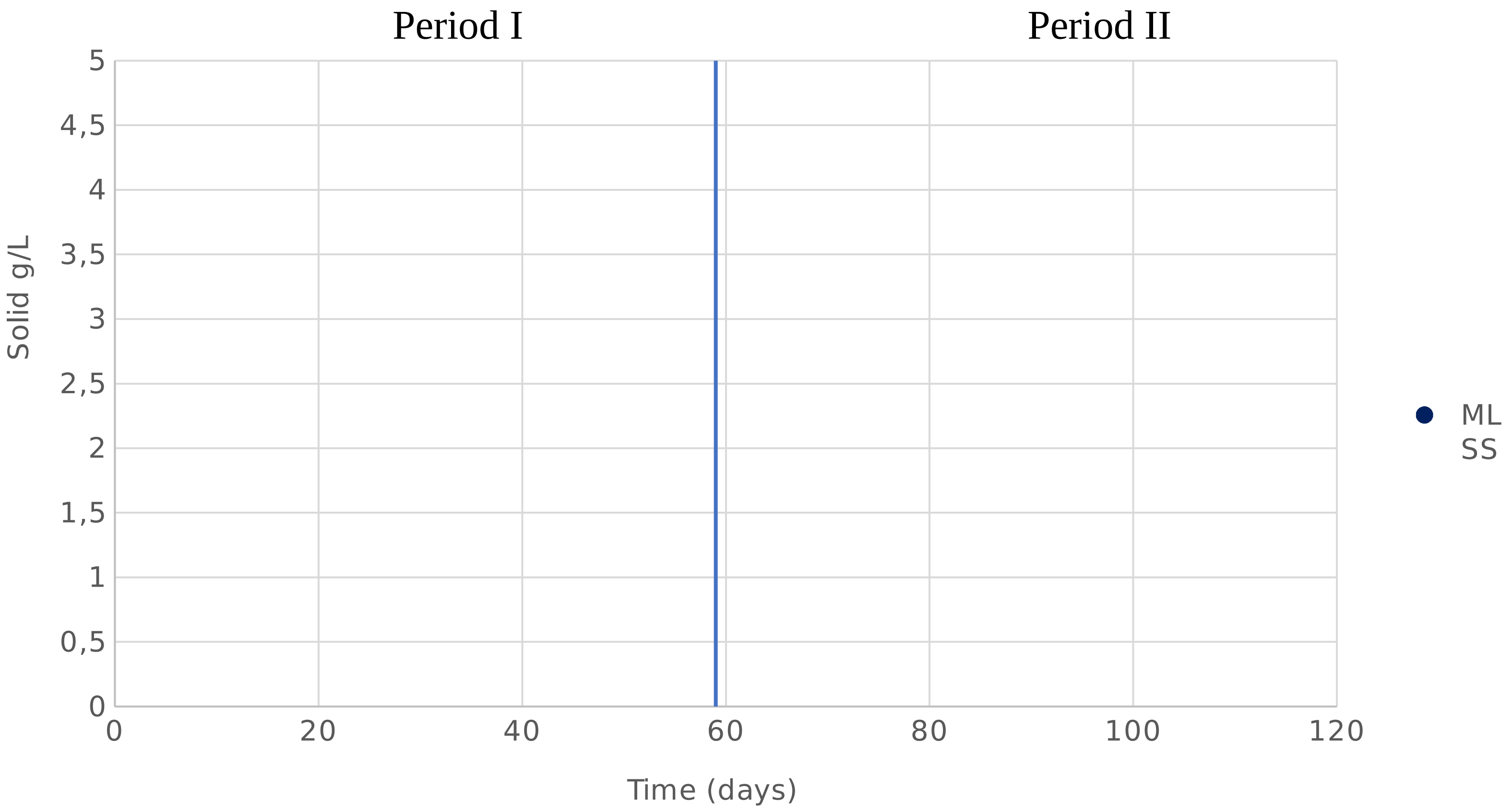
Results

Selection Sequencing Batch Reactor (SBR I)



Results

Processing the biomass after accumulation in SBR II

1

Total volume	900 L
TS	1,6 g/L
TS mass	1,44 Kg

Biomass after accumulation step

2

Rotative membrane

0,25 µm pore size

Storage tank

4

3

Total volume	888 L

Permeate

5

Volume	12 L
TS	85 g/L
TS mass	1,02 Kg

Thickened sludge

6 Centrifuge

Volume	12 L
TS	85 g/L
TS totali	1,02 Kg

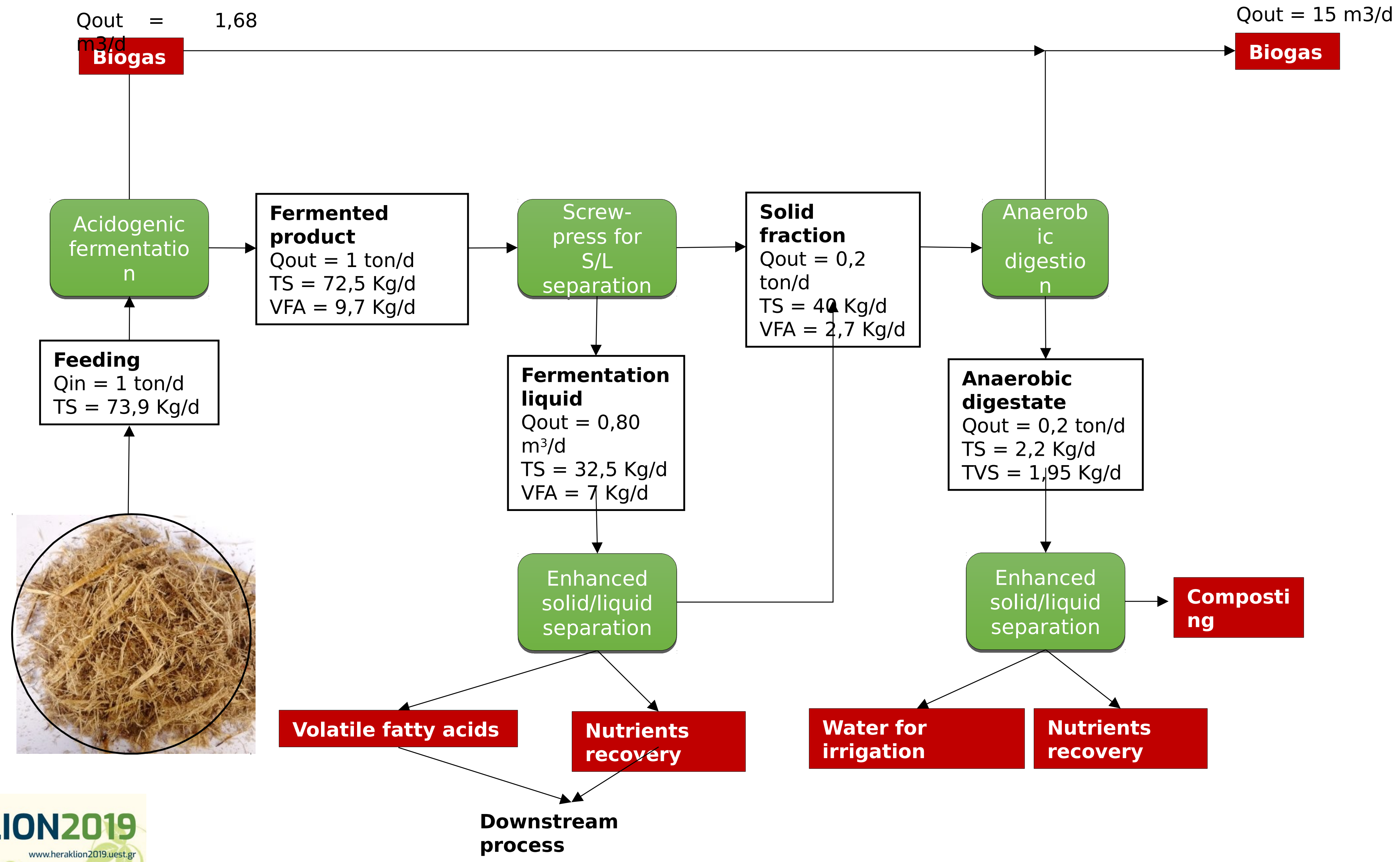
Volume of permeate	6 L

7 Extraction step

Volume	6 Kg
TS	171 g/Kg
TS totali	1,02 Kg

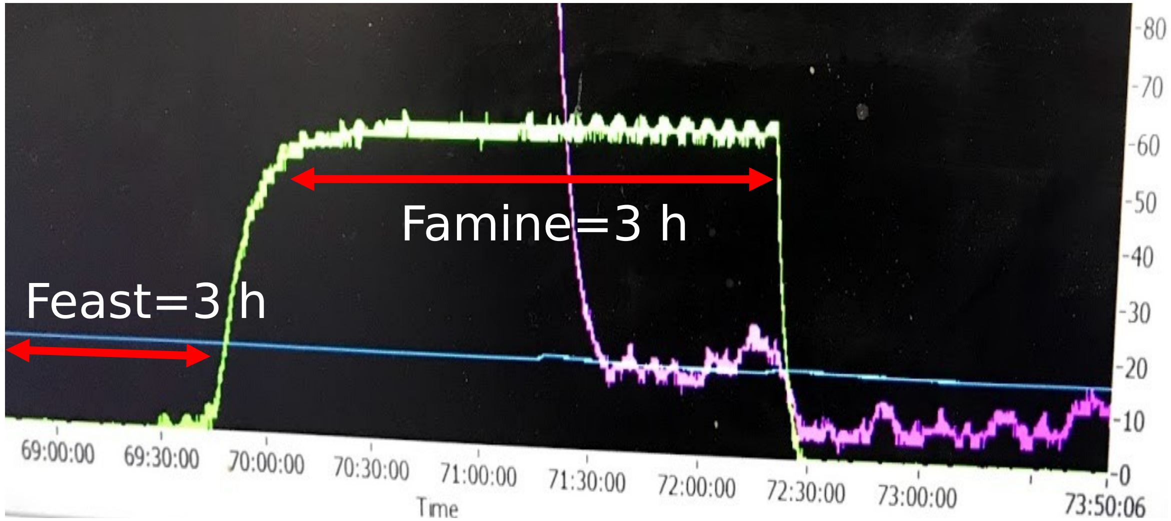
Thickened sludg

The mass balance



Response of the PHA selection biomass on the Feast to famine ratio

Period I



Durata ciclo 6h

Period II

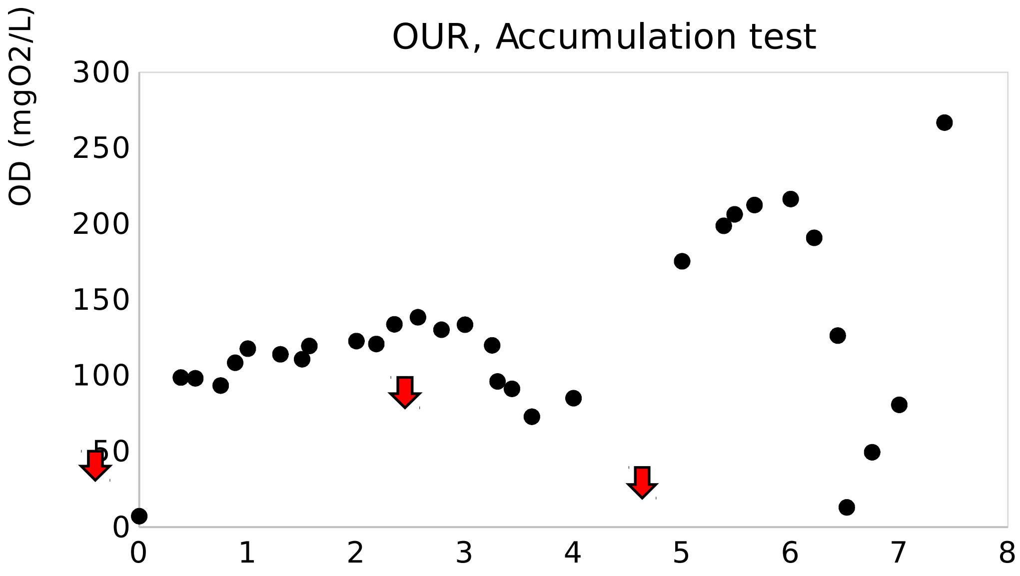
Durata ciclo 15h

SBR I	Unit	Period I (0-59)	Period II (60-93)
feast/Famine	-	1	0,16
VFAs end of the cycle	mgO_2/L	1000 ± 0,33	1,03 ± 0,13
MLSS	g/L	1,9 ± 1	2,31 ± 0,4
MVLSS	g/L	1,51 ± 0,9	1,98 ± 0,3

Operative Conditions

Parameter	Unit	SBR I Period I (0-55)	SBR II Period II (56-95)
Working volume	m3	2	2
OLR	kgCOD/m3 d	3,5	0,85
COD/N	kgCOD/kgN	22	12
SRT=HRT	d	4	10
Temperature	°C	15-20	20-25

Julie



OUR, Accumulation test
OD (mgO2/L)
300
250
200
150
100
50
0
0
1
2
3
4
5
6
7
8