Two-phase thermophilic anaerobic co-digestion of organic waste and activated sludge: process optimization for bio-hythane production in a integrated waste-wastewater treatment approach.

Cristina Cavinato[1], Francesco Fatone [2], David Bolzonella [2], Paolo Pavan[1]

University Ca' Foscari of Venice

University of Verona

INTRODUCTION

Considering the energy production scenario of next years, three are the main points to consider to develop sustainable systems according to environmental concerns:

•the CO_2 emissions reduction when fossil fuels are used;

•the energy saving by optimisation of the actual industrial processes;

•energy production from renewable sources.

Energy production from renewable sources: organic waste

Dry substrates

Wet substrates

ANAEROBIC DIGESTION

BIOGAS (CH_4, CO_2)

Process optimisation in order to obtain a real alternative to traditional systems.

Obtain H_2-enriched biogas, using a separate controlled fermentative step before methanogenesys. This approach can lead to the production of *bio-hythane*.

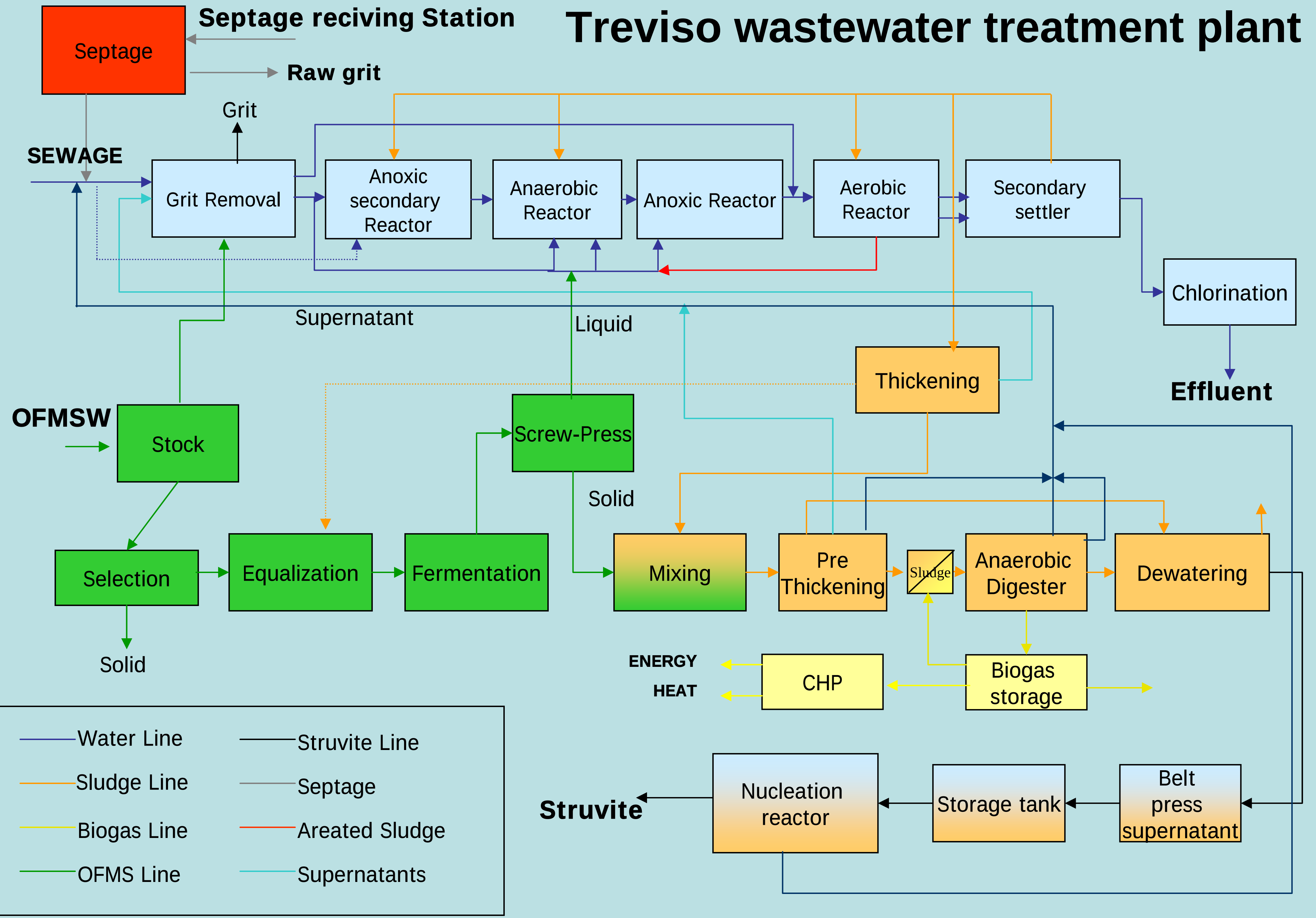
Porpatham E. et al. International Journal of Hydrogen Energy (2007)

- **The lean misfire limit of combustion of biogas under actual engine operating conditions gets considerably extended with hydrogen addition. The combustion rate also is enhanced.**
- **There is an improvement in thermal efficiency and power output with very lean mixtures and a hydrogen concentration of 15%.** However, there was a need to retard the ignition timingto avoid knock with rich mixtures. This leads to low thermal efficiency and reduced power output at these conditions.
- **A drastic reduction in HC emissions is seen with 10% hydrogen addition.** This is mainly due to the improvement in combustion by way of extension of the lean limit and increase in the combustion rate. HC level drops from 1530 ppm with neat biogas to 660 ppm with 10% hydrogen at an equivalence ratio of 0.95.
- **The addition of hydrogen to biogas does not necessarily lead to any significant increase in the NO level since the CO2 acts as a diluent** and also there is a need to retard ignition timings with near stoichiometric mixtures to avoid knock.
- There is a significant drop in the COV of IMEP with lean mixtures with hydrogen addition. The COV of peak pressure and standard deviation of peak pressure start rising at the onset of knock. At this condition the few cycles that knock show significant differences from the average cycle.
- Peak pressures and MRPR do not increase with hydrogen addition as the spark timing is retarded to avoid knock.

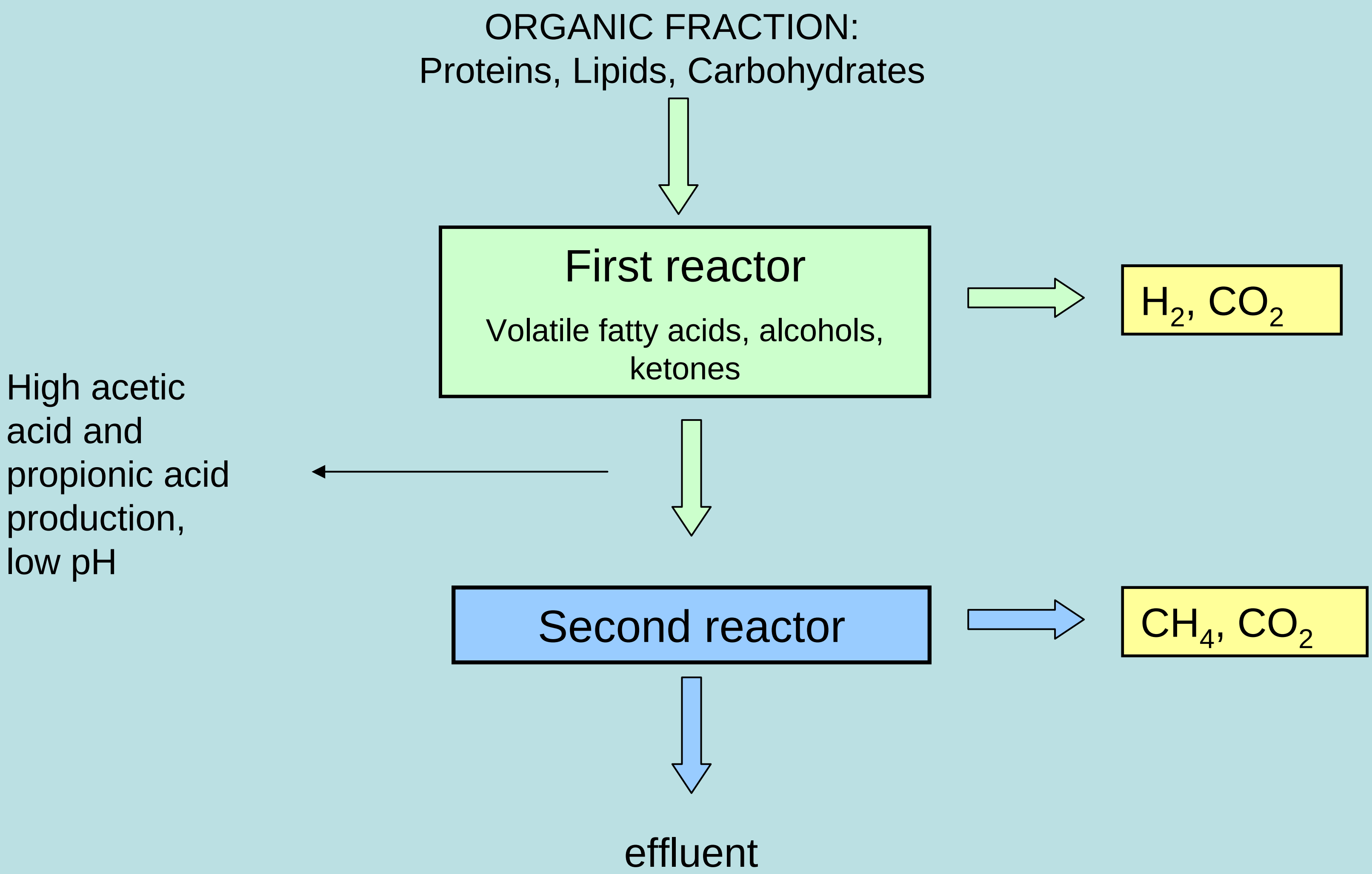
Treviso wastewater treatment plant

Equivalent inhabitants:	**50.000+20.000**
OFMSW capacity:	**up to 20 tons/d**
Hydraulic loading:	**14.000+9.600 m3/d**
Organic loading:	**3.570+1.200 KgBOD/d**
Nitrogen loading:	**602+241 KgN/d**
Phosporous loading:	**84+34 KgP/d**
F/M (ox):	**0.125 KgBOD/KgMLSS**

Treviso wastewater treatment plant



The aim of this work is to optimise a two phase thermophilic anaerobic digestion process for bio-hythane production treating source collected organic fraction of municipal solid waste, using a conventional two-phase A.D. approach.


ORGANIC FRACTION:
Proteins, Lipids, Carbohydrates
First reactor
Volatile fatty acids, alcohols, ketones
H_2, CO_2
High acetic acid and propionic acid production, low pH
Second reactor
CH_4, CO_2
effluent

MATERIAL AND METHODS

Substrate characteristics

The organic fraction of municipal solid waste, obtained by mechanical selection of source collected waste of Treviso’s municipality (northern Italy). This material is suitable for anaerobic digestion process thanks to its high biomethanisation potential.

	units	average	max	min	s.d.
TKN	(mgN/kg)	5876,6	6338,8	5397,1	471,1
P_{tot}	(mgP/kg)	544,6	733,3	352,0	190,7
COD	(gCOD/kg)	234,8	254,3	205,5	25,8
TS	(g/kg)	270,3	304,7	234,7	29,6
TVS	(g/kg)	205,5	232,5	187,3	20,1
TVS	(%TVS,TS)	77,0	85,6	61,5	11,4

Experimental setup: FIRST phase reactor

Reactor: CSTR, stainless steel (AISI 304)

Volume: 200 lt

Temperature: 55°C

Feed: semicontinously

HRT: ~6 days

FERMENTATIVE STEP

⇒ CO_2 and H_2 production

Experimental setup: SECOND phase reactor

Reactor: CSTR, stainless steel (AISI 304)

Volume: 380 lt

Temperature: 55°C

Feed: semicontinously

HRT: ~12 days

INOCULUM: anaerobic digested sludge coming from the full scale digestor of Treviso WWTP

METHANISATION

→ CH_4 and CO_2 production

Operative conditions of whole experimental work

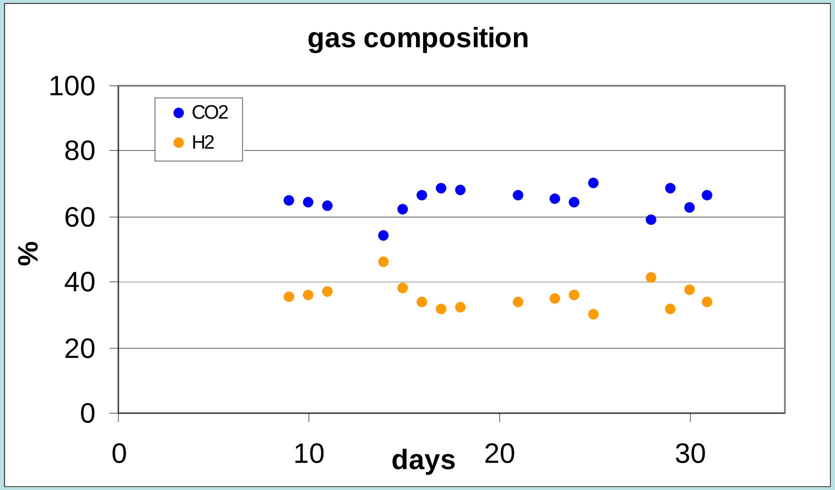
Working period:	1	2
HRT fermentative step, d	3,3	6,7
HRT methanogenic step, d	12,6	12,6
OLR fermentative step, kgTVS/m^3 d	20	20
OLR methanogenic step, kgTVS/m^3 d	5	10

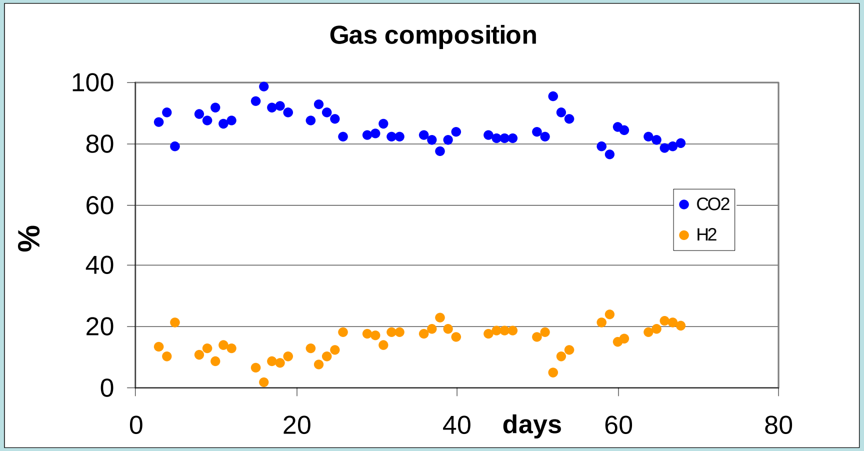
- The overall HRT of the system can be considered in the same range of the one used for single phase process.

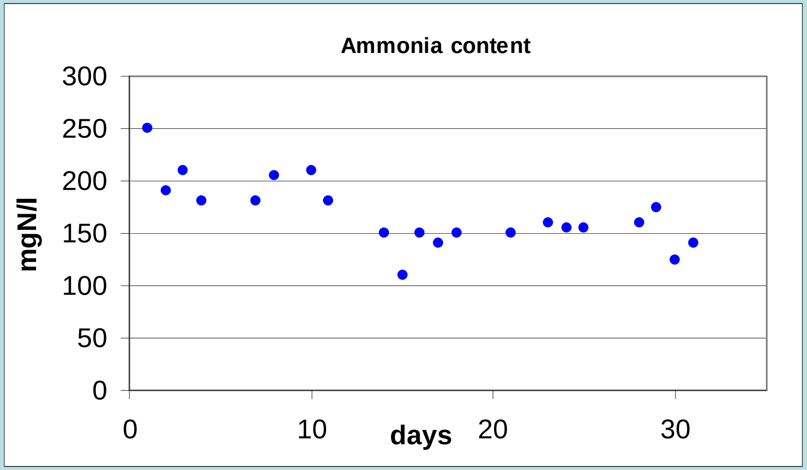
RESULTS: FERMENTATIVE STEP

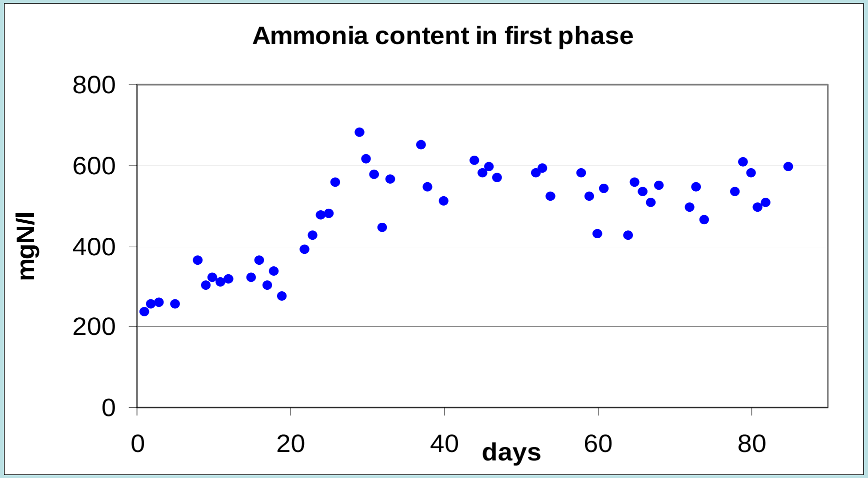
	units	1° period	2° period
pH		3,51	4,32
NH_3	(mg N/L)	152,2	530,8
VFA	(mg COD/L)	2641,1	7605
TKN	(mgN/L)	2009,2	4720,8
P_{TOT}	(mg P/L)	291,3	758,2
COD	(g COD/L)	66,9	157,9
TS	(g/L)	78,0	172,2
TVS	(g/L)	67,4	142,4
TVS	(% TVS,TS)	86,4	82,7

RESULTS: FERMENTATIVE STEP





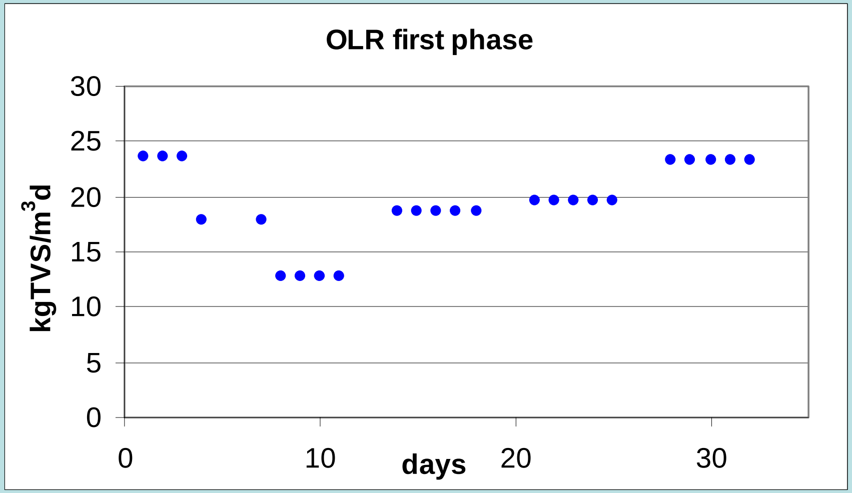


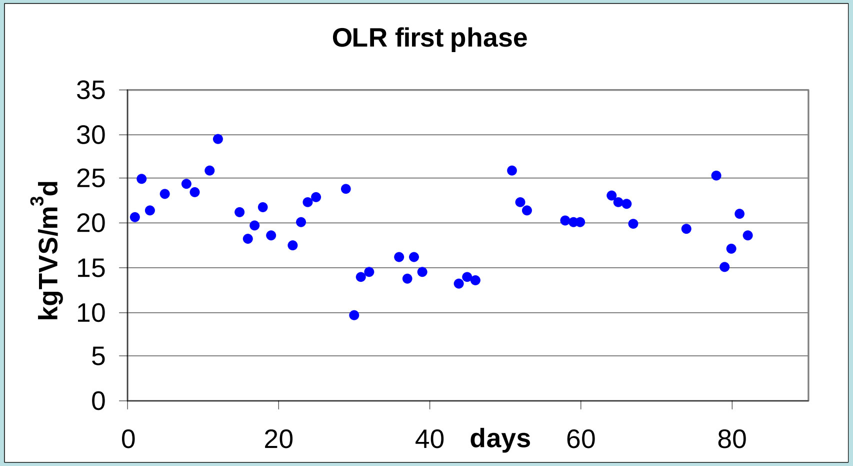


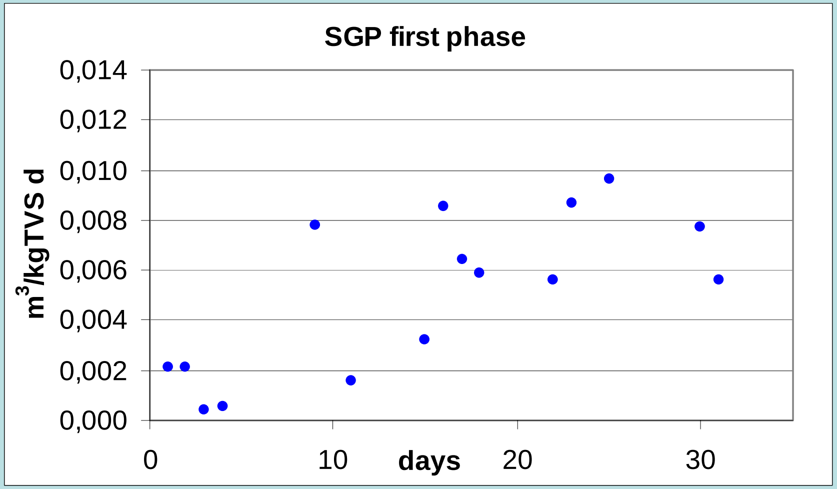
1° period RESULTS: FERMENTATIVE STEP-yields

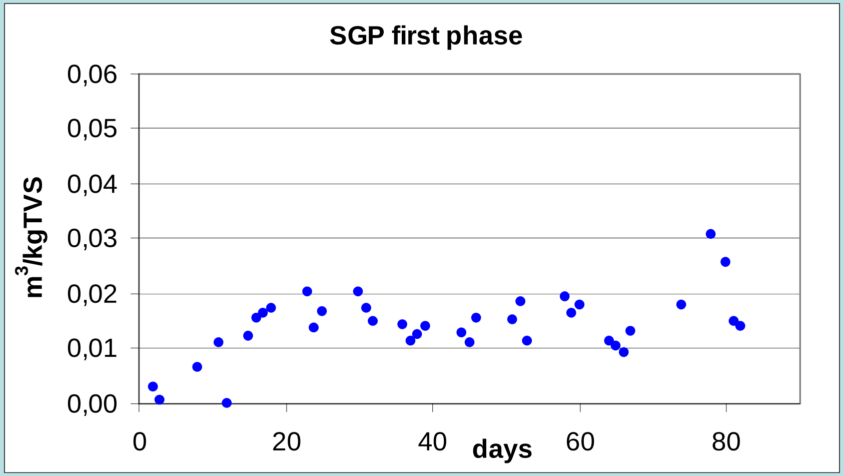
	units	1° period	2° period
CO_2	(%)	65,51	84,93
H_2	(%)	34,49	15,08
GPR $_{1° \text{ phase}}$	$(m^3/m^3_r\, d)$	0,15	0,37
OLR $_{1^a \text{ phase}}$	$(KgTVS/m^3 d)$	21,01	20,6
SGP $_{1° \text{ phase}}$	$(m^3/kgTVS_f)$	0,007	0,019
SHP	$(m^3H_2/kgTVS_f)$	0,003	0,003

RESULTS: FERMENTATIVE STEP-YIELDS





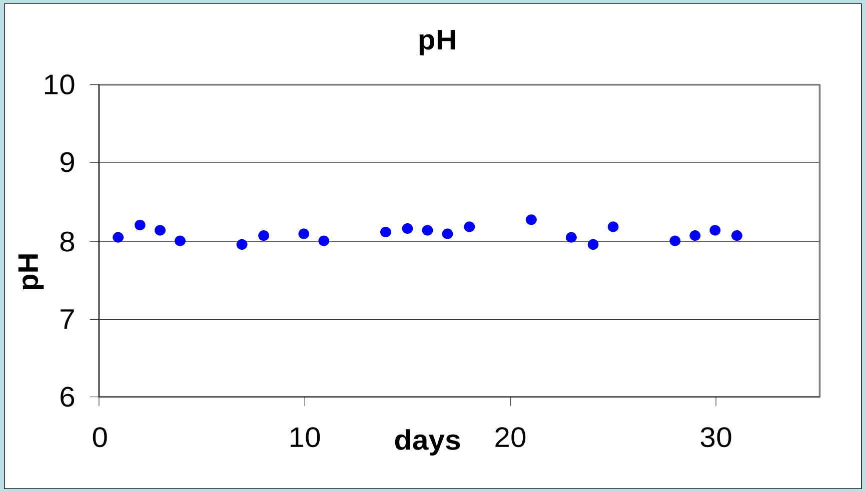


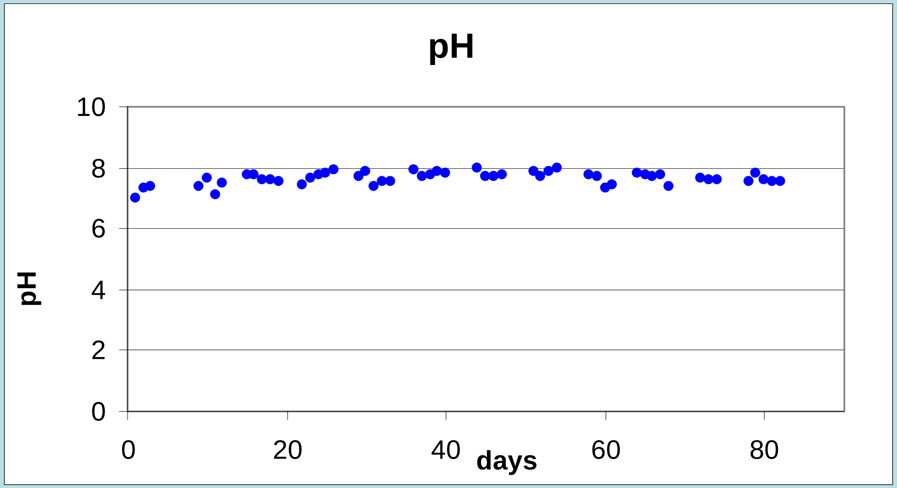


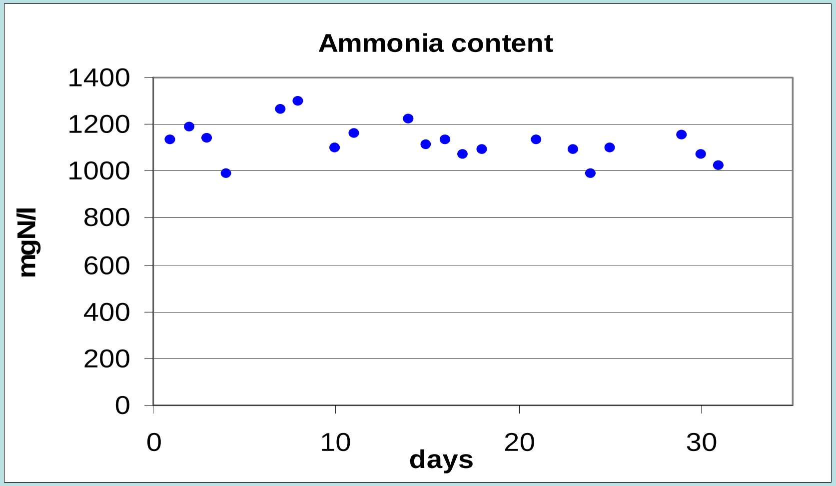
RESULTS: METHANOGENIC REACTOR-stability parameters

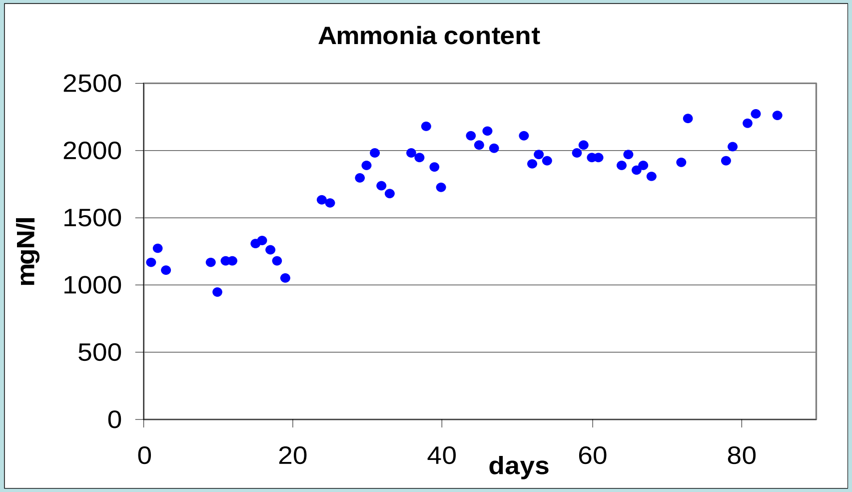
	units	1° period	2° period
pH		8,09	7,68
Alkalinity (pH6)	($mgCaCO_3/L$)	2726,6	4823,2
Alkalinity (pH4)	($mgCaCO_3/L$)	5316,0	10085,3
NH_3	(mg N/L)	1047,8	1955,3
VFA	(mg COD/L)	611,3	223,3
TKN	(mgN/L)	1015,8	2388,5
P_{TOT}	(mg P/L)	216,1	486,3
COD	(g COD/L)	24,2	60,7
TS	(g/L)	29,3	75,6
TVS	(g/L)	21,0	56,8
TVS	(% TVS,TS)	71,1	75,2

RESULTS: METHANOGENIC REACTOR-stability parameters





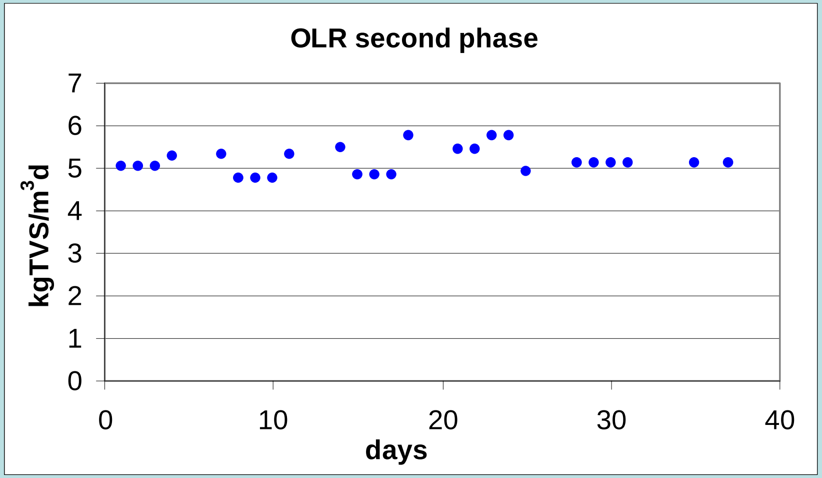


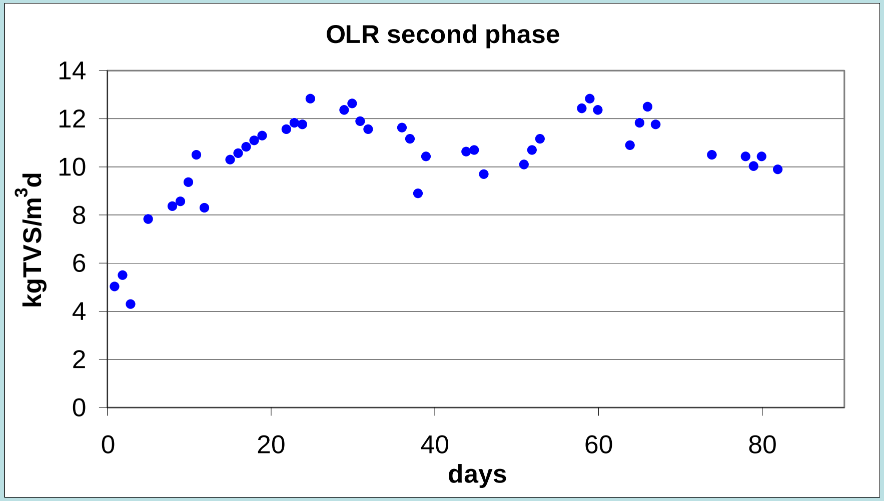


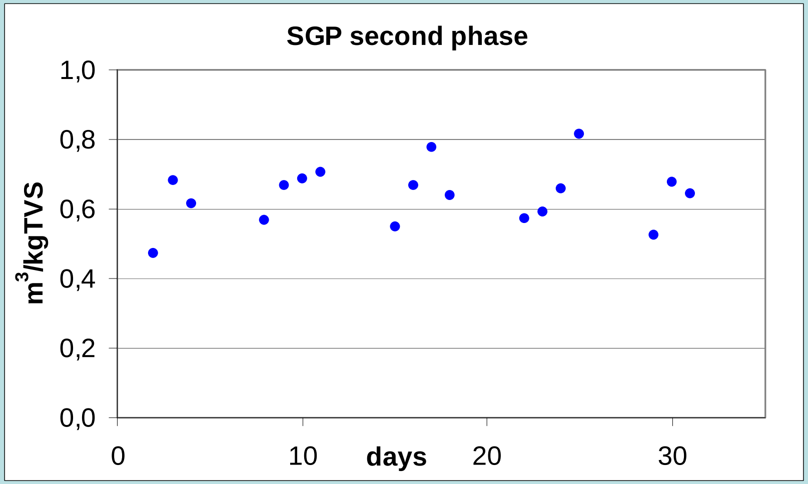
RESULTS: METHANOGENIC REACTOR- yields

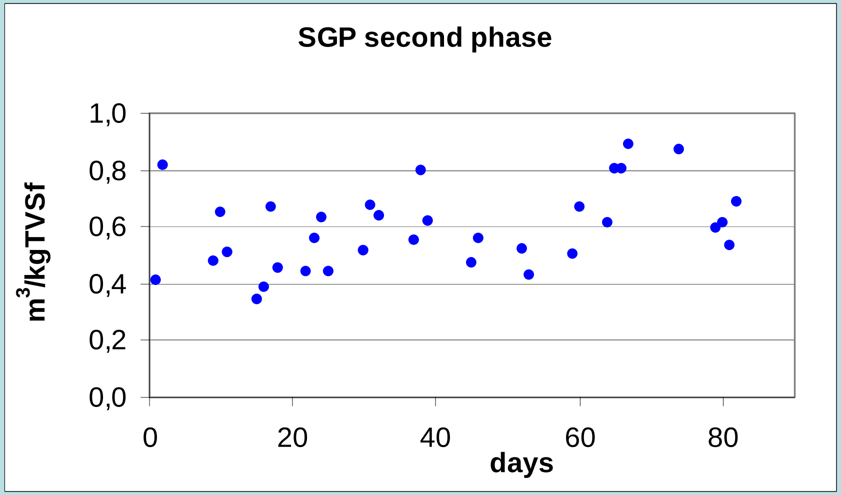
	units	1° period	2° period
CO_2	(%)	33,71	33,85
CH_4	(%)	59,81	65,38
GPR $_{2°\ phase}$	$(m^3/m^3_r\ d)$	3,43	7,32
OLR $_{2^a\ phase}$	$(KgTVS/m^3d)$	5,36	11,25
SGP $_{2°\ phase}$	$(m^3/kgTVS_f)$	0,64	0,66

RESULTS: METHANOGENIC REACTOR- yields









CONCLUSION

The two phase conventional A.D. approach, using OFMSW as substrate, can be used as Hythane production process, without any chemicals additions in the control of the phases balancement;

Hydrogen yields obtained are quite low (SHP =0.003, m3H2/kgTVSf), but several possibility of improvement could be obtained by process optimisation (adopting different HRT and OLR values);

In any case, the use of a prefermentation step lead to better performance in terms of yields and stability, allowing high values of methane production from this kind of substrate (GPR=7.3 m3/m3 d, SGP=0.66 m3/kgTVSf), thanks to the optimal grow environment reached dividing the phases;

The two phase approach confirm the possibility to use high OFMSW load conditions in both phases, without any stability problem (more than 8500 mg/l of VFA in the 2° phase inlet, less than 300 mg/l in the outlet). This lead to smaller reactors, even if a double unit is required;

Very high buffering capacity are reached in methanogenic step (more than 10000 mgCaCO3/L);

The system seems to need a long time to reach real SSC: more experimental work is needed to evaluate the best operative conditions to be used.

THANK YOU FOR YOUR ATTENTION