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Biogas enhancement through a TPAD carried out on primary sludge

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Feedstock \ Pretreatment	Mechanical	Thermal	Chemical	Biologic.
SLUDGE	Sonication High pressure Lysing centrifude Focused pulsed technique	Steam explosion Hydrothermal		
Animal by-products	Grinding	Hydrothermal Low temperature	Saponification	
Manure	Grinding Extrusion Maceration			Partial composting
	Nitrogen extraction			
Municipal solid waste	Grinding Maceration Extrusion	Steam explosion		Pre composting
Agricultural residues Energy crops	Grinding Extrusion		Alkali	Enzymes Ensiling Composting Fungi
Algae		Low temperature		

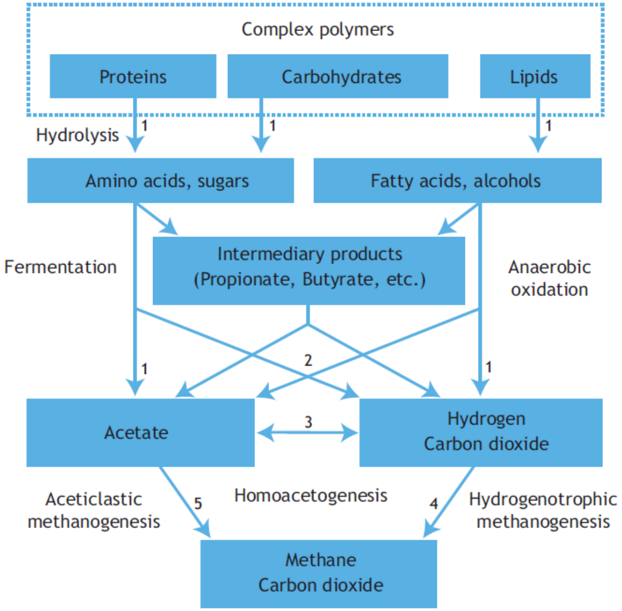
Full-scale application | Pilot-scale application | Promising lab-scale results

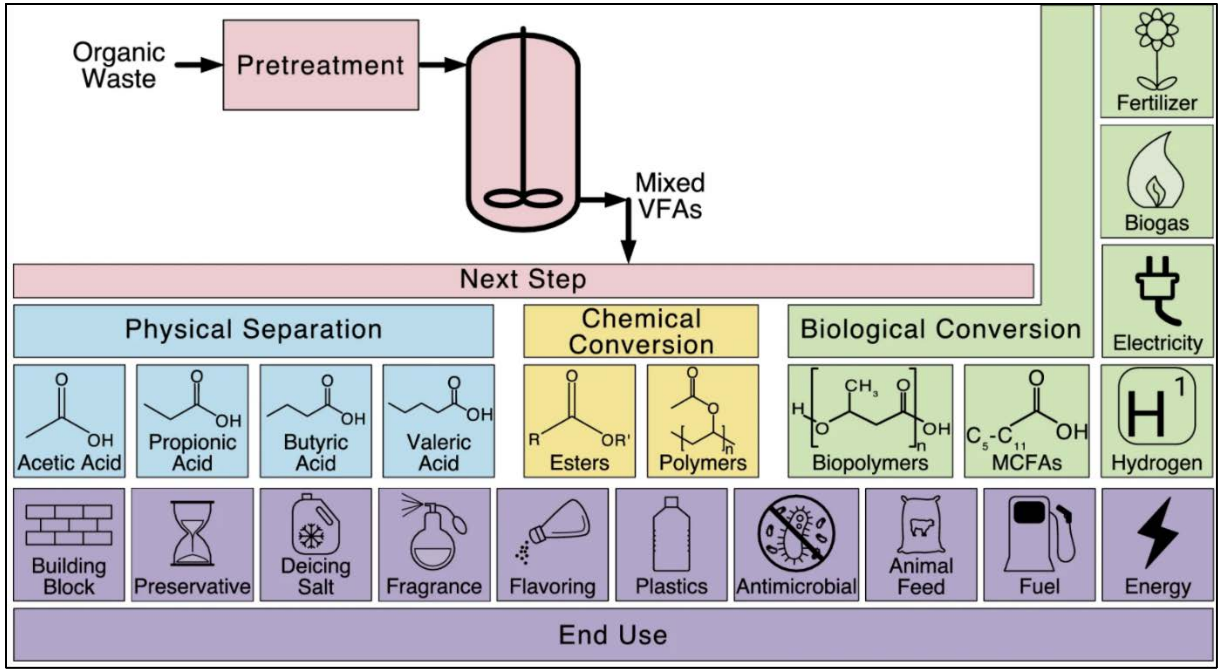
Carrere H., Antonopoulou G., Affes R., Passos, Battimelli A., Lyberatos G,Ferrer I. (2016) Review of feedstock pretreatment strategies for improved anaerobic digestion: From lab-scale research to full-scale application Bioresour. Technol.Vol. 199, 386–397

Ttemperature **P**phased **A**anaerobic **D**digestion

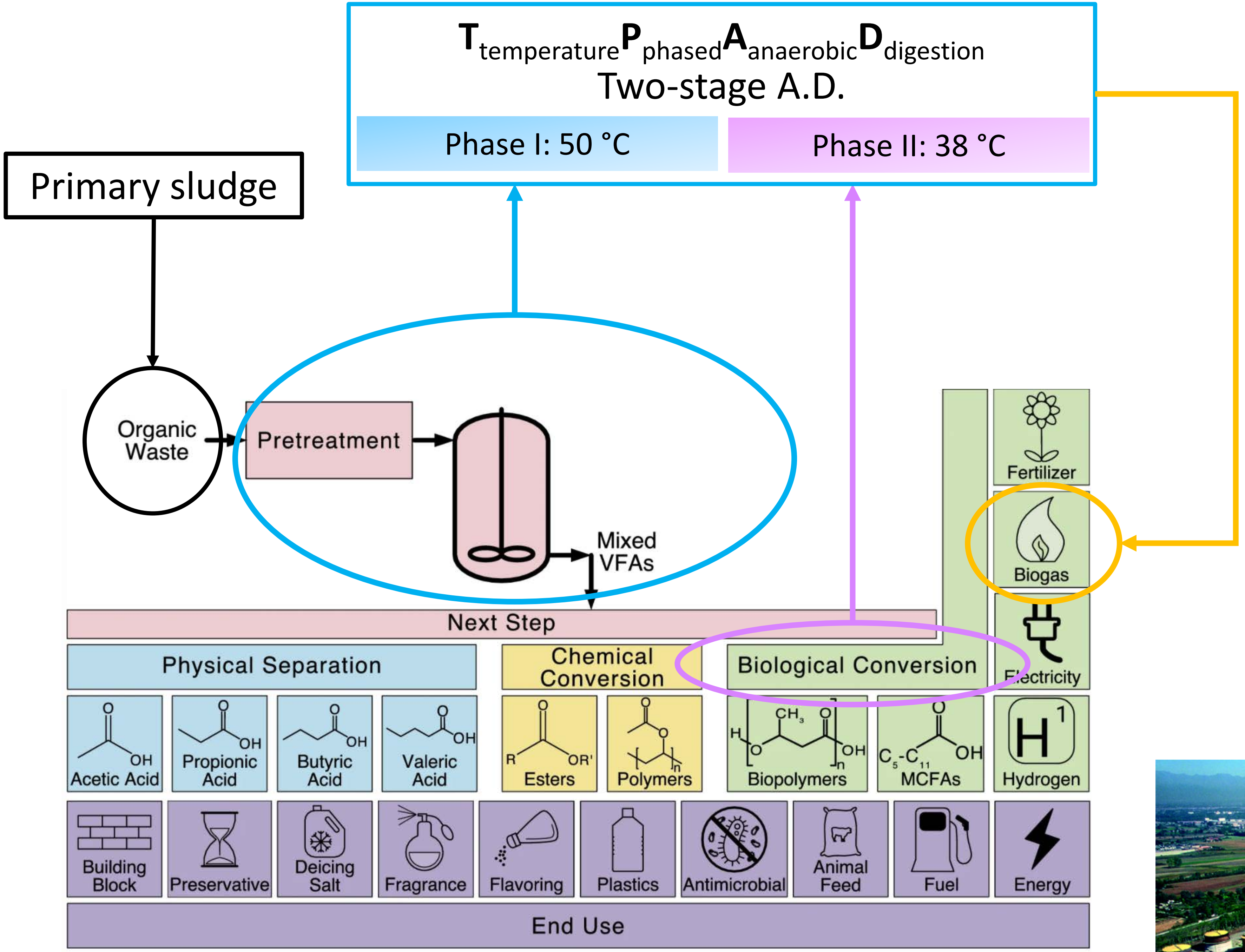
Two-stage A.D.

Phase I: 50 °C	Phase II: 38 °C
HRT 2 days	HRT 20 days





Maria Ramos Suarez et al; Reviews in Environmental Science and Bio/Technology; 20 (2021)



Adapted from Maria Ramos Suarez et al; Reviews in Environmental Science and Bio/Technology; 20 (2021)

In this work:

reliable SMP data

energy assessment

Castiglione Torinese SMAT
WWTP 2,300,000 e.p.

Materials and Methods

AD tests

One-stage, semicontinuous, AD test
Control reactor

TPAD
Two stage, semicontinuous, AD test

Duration	3 months
Feed collections	11

Materials and Methods

Average elemental composition of the PS used in the study.

	N (%)	C (%)	H (%)	O (%)
TS	4.568	41.819	6.048	46.994 (*)
FS	<DL	0.546	0.253	ND

FS, fixed solids (TS – VS); DL, detection limit; ND, not determined
(*) The oxygen amount was calculated as 100 minus the sum of the amounts of C, N, H.

Substrate: **Primary** sludge

Ruffino B., et al; Energy Conversion and Management; 223 (2020)

$$tCOD = \frac{8(4n + a - 2b - 3d)}{(12n + a + 16b + 14d)} as\left(\frac{gCOD}{gC_nH_aO_bN_d}\right) = 1{,}65\ \frac{g\ O_2}{g\ VS}$$

$$\frac{_sCOD}{_tCOD} = 5\ \%$$

smat gruppo

Castiglione Torinese SMAT WWTP 2,300,000 e.p.

Sludge line:
from pre-thickeners
to digesters

Primary sludge samples
Thickened from 2,5 to 3,1% TS

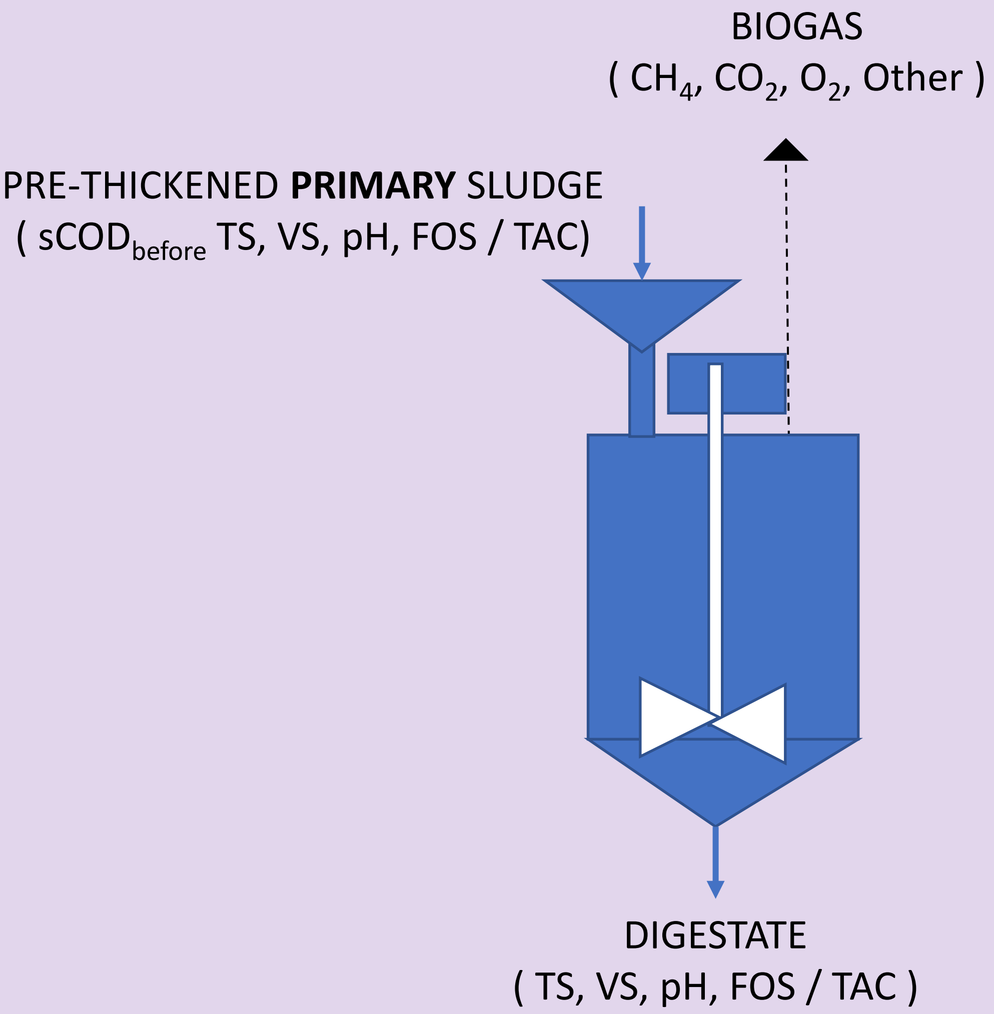
Materials and Methods

One-stage semicontinuous digestion test

↓

Control reactor

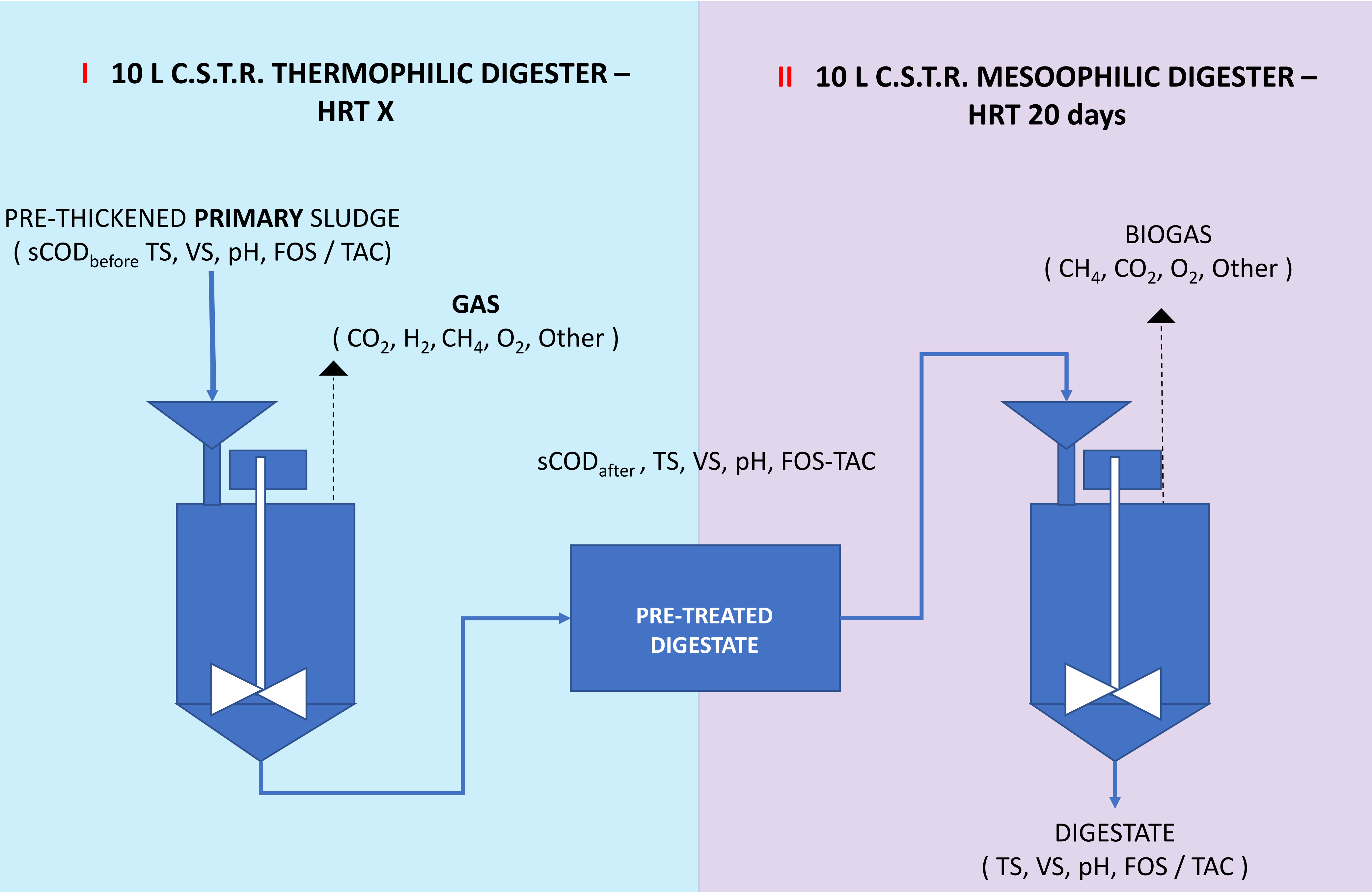
10 L C.S.T.R. MESOPHILIC DIGESTER – HRT 20 days



Materials and Methods

TPAD
Two stage AD test

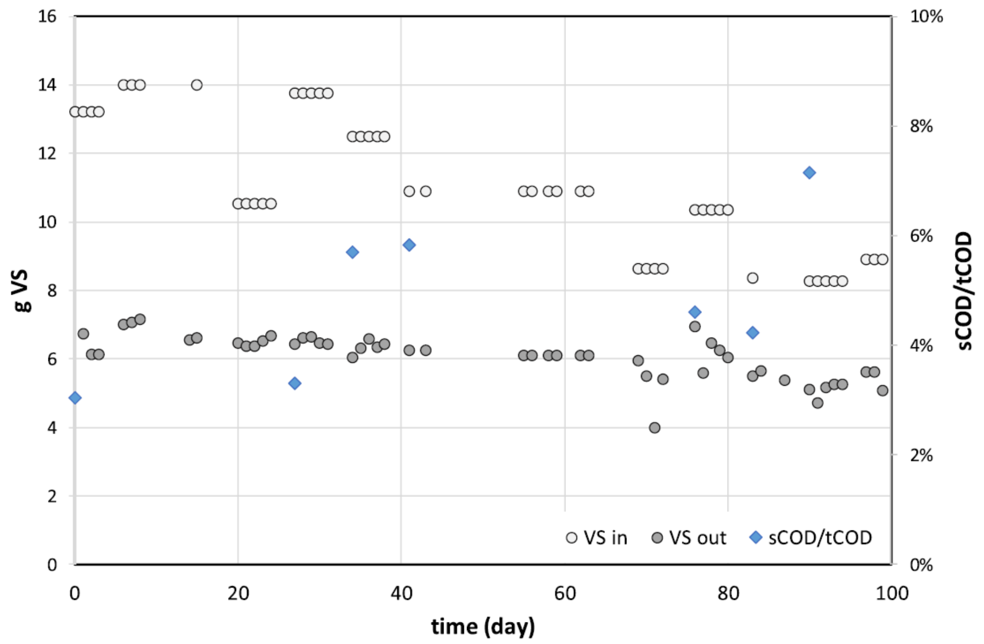
10 L C.S.T.R. H.R.T. X	
1st Period	3 days
2nd Period	2 days

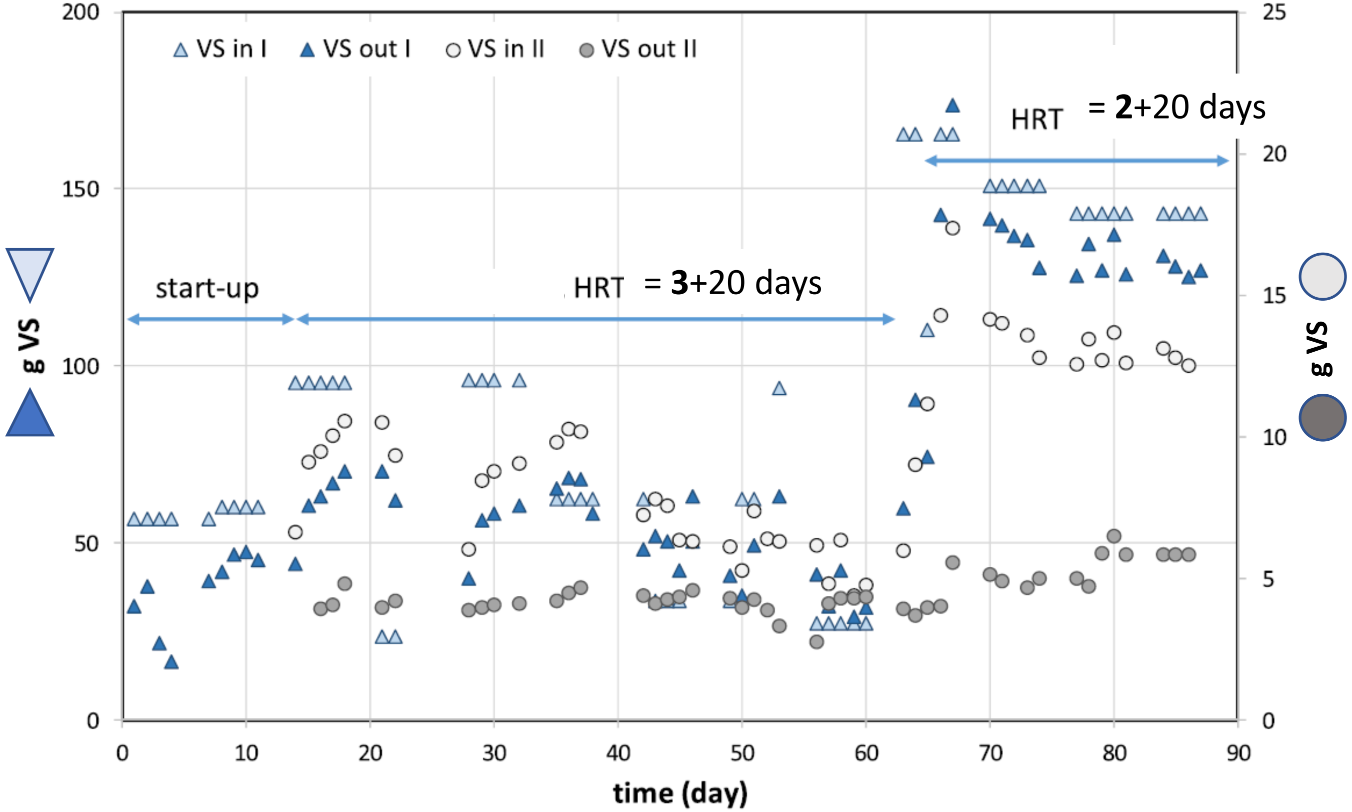


Results

VolatileSolids in – VS out

ONE-STAGE A.D. HRT 20 days	VS removal
M. R.	42 %





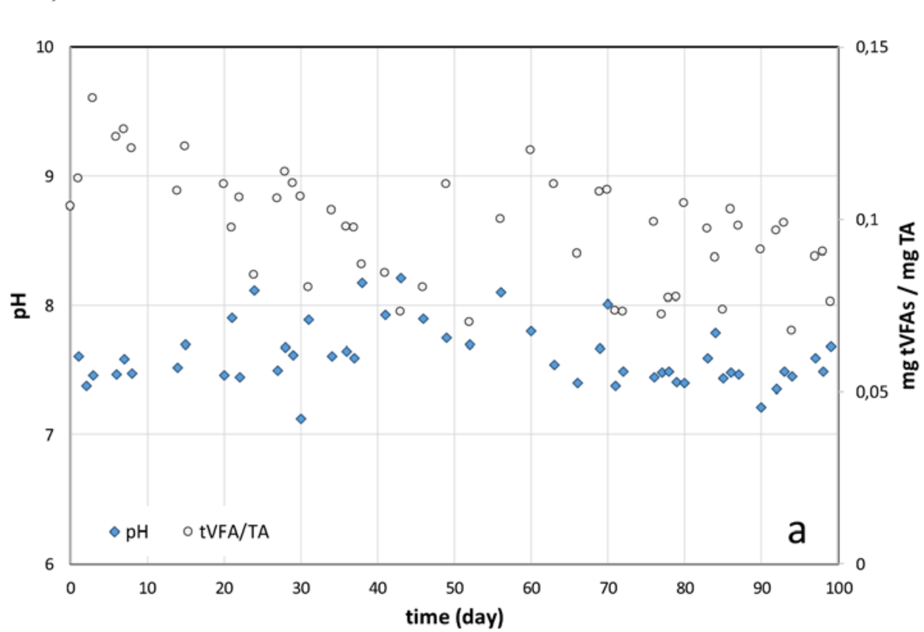
TWO-STAGE A.D. HRT 2+20 days	VS removal
Acid Reactor	11%
Mesophilic Reactor	57%
A. R. + M. R.	62,2%

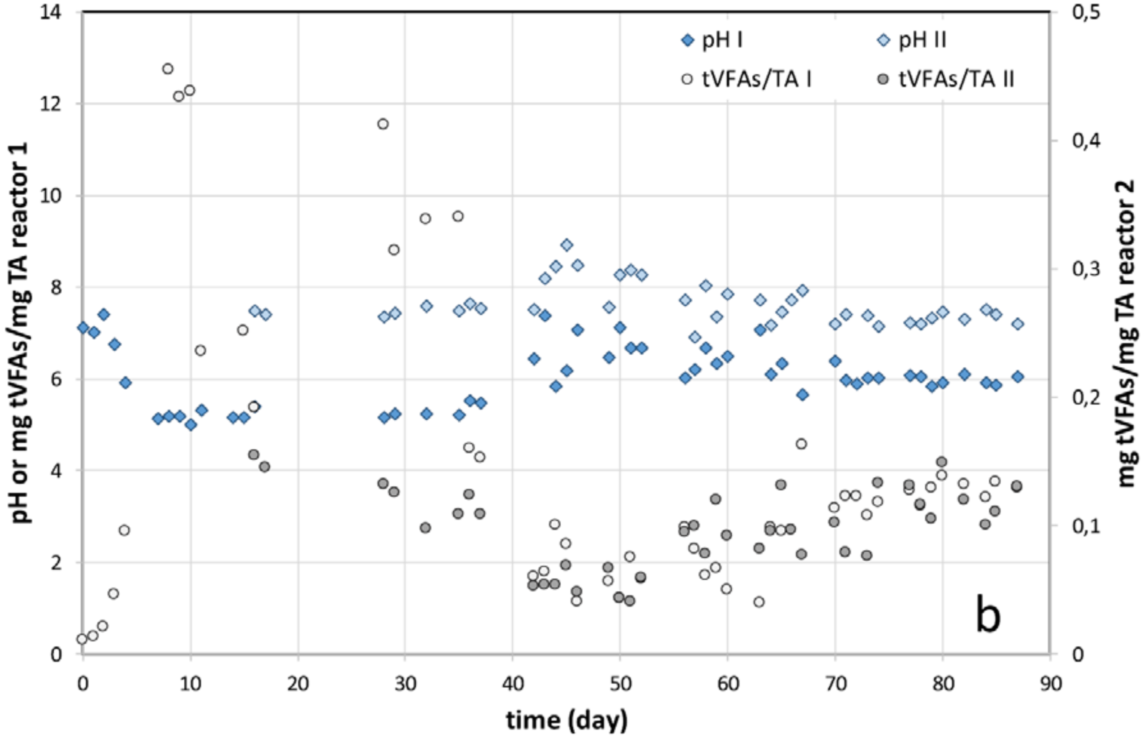
+ 48%

Ruffino B., et al; Energy Conversion and Management; 223 (2020)

Results
Process stability

ONE-STAGE A.D. HRT 20 days	
pH	7,59 ± 0,24
mg tVFAs / mg TA	0,10

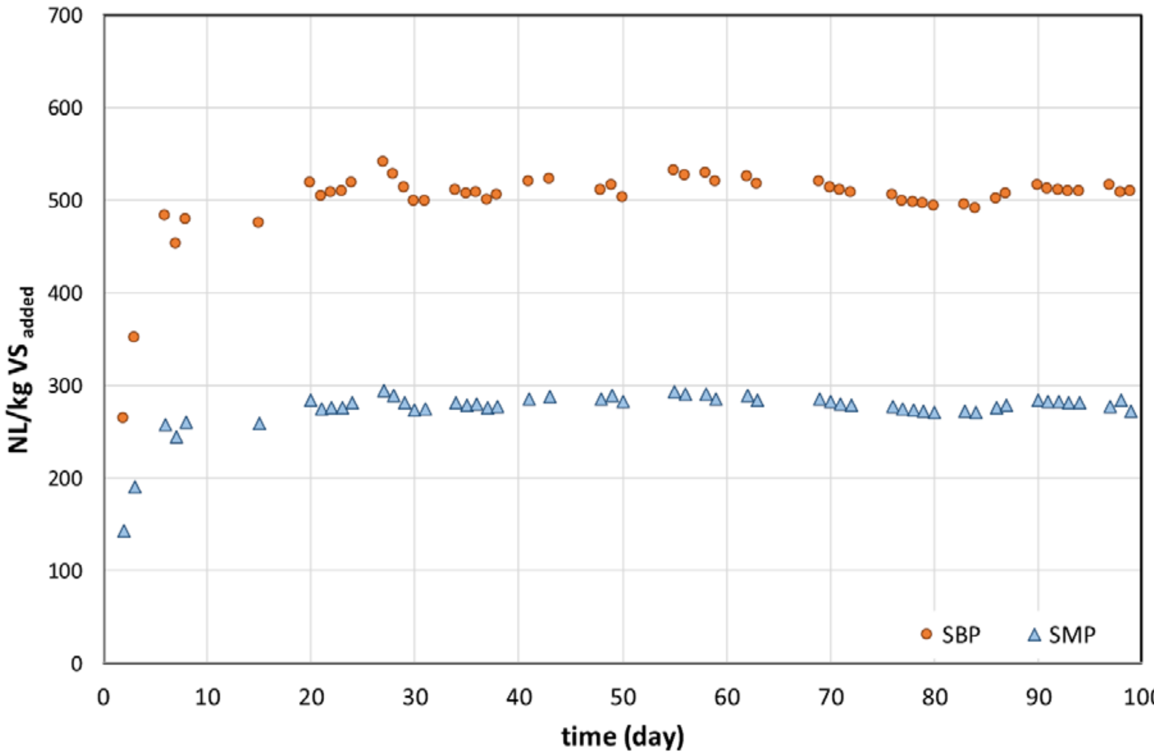


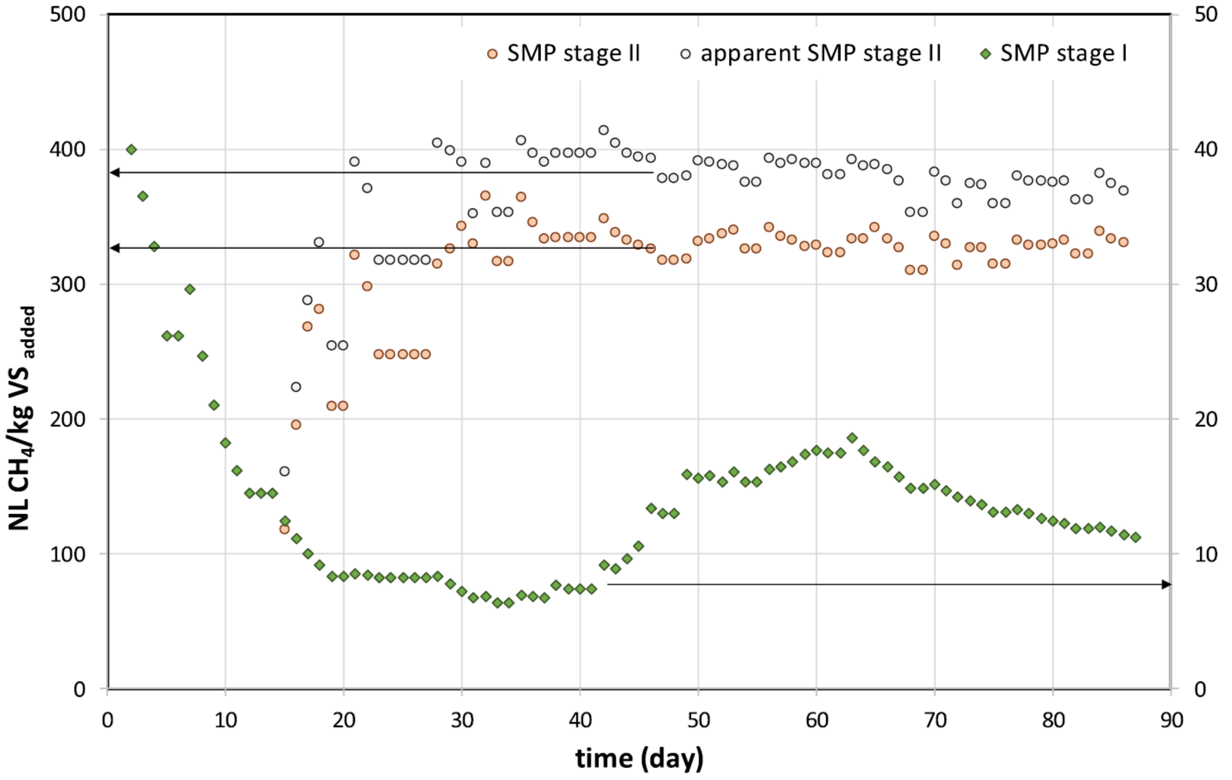


TWO-STAGE A.D. HRT 2+20 days	pH	mg tVFAs / mg TA
Acid Reactor	6,02 ± 0,67	2,52 ± 0,94
Mesophilic Reactor	7	0,1

Results Methane production

ONE-STAGE A.D. HRT 20 days	NL / kg VS
SBP	511,6
SMP	280,6
CH_4	55,0%





TWO-STAGE A.D. HRT 2+20 days	SMP NL / kg VS	
Acid Reactor	12,8	
Mesophilic Reactor	(apparent) 372 X	

Results Methane production

ONE-STAGE A.D. HRT 20 days	NL / kg VS
SBP	511,6
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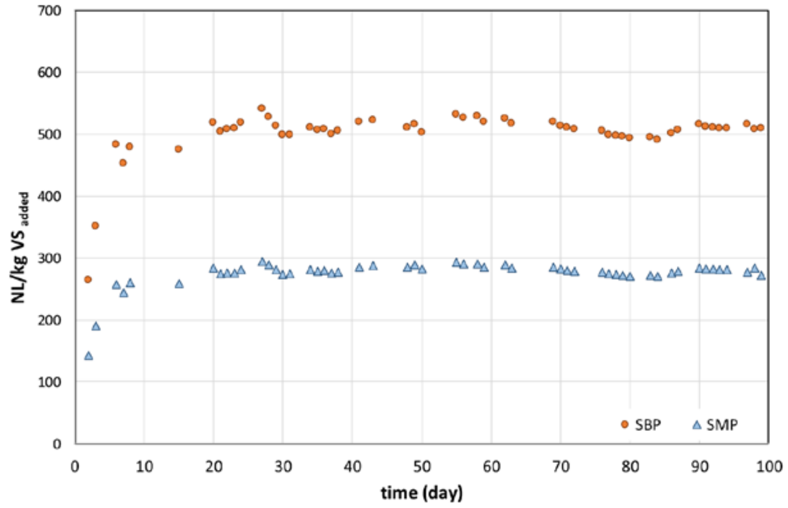
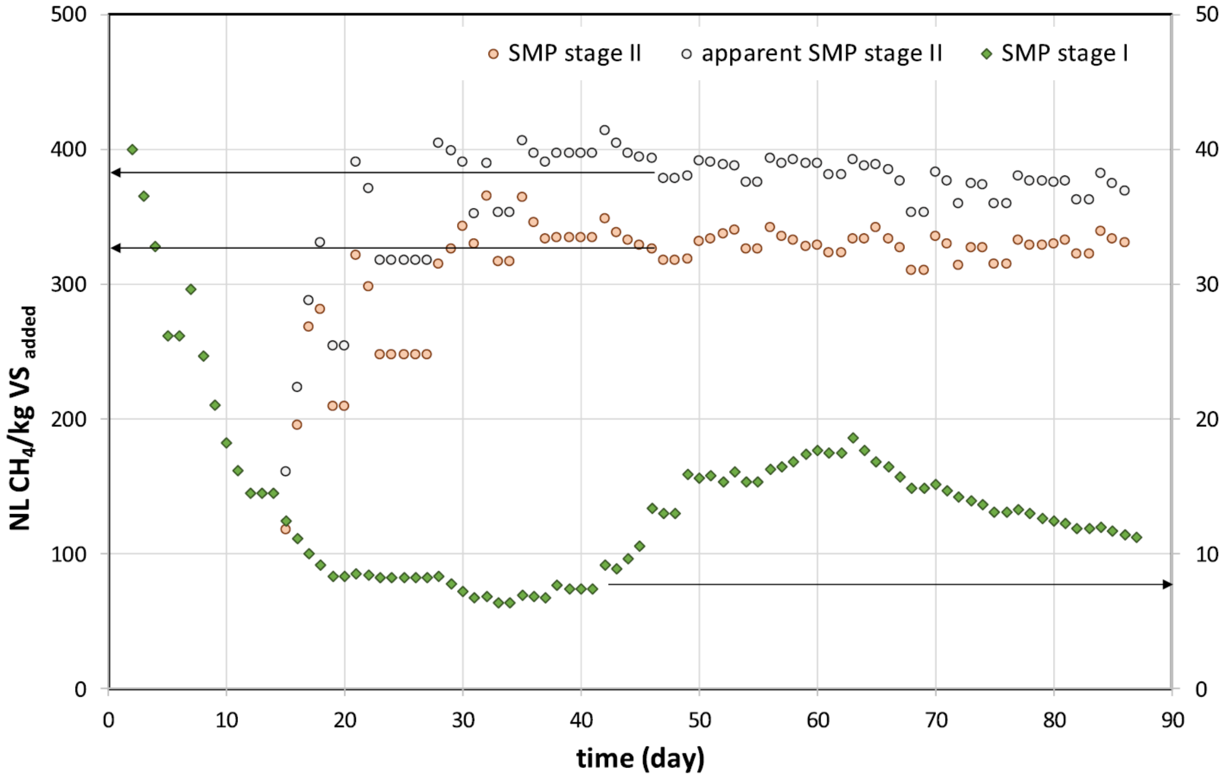
CH_4	55,0%





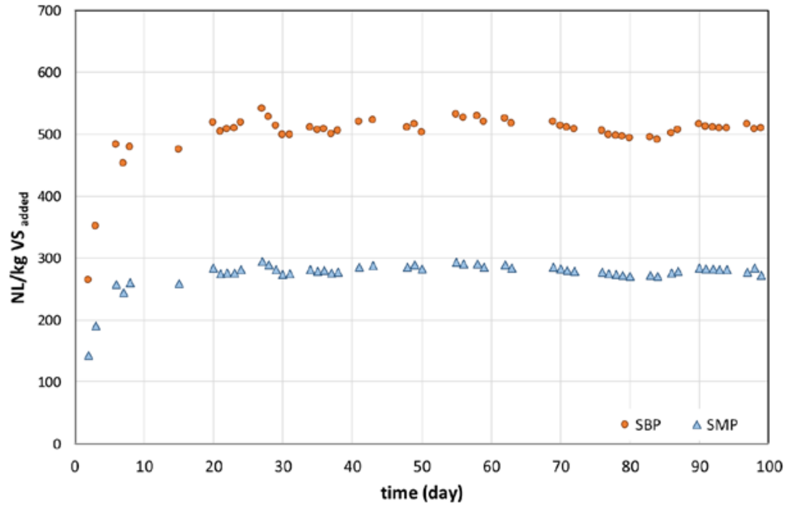
TWO-STAGE A.D. HRT 2+20 days	SMP NL / kg VS	$B' = B_0 (1 - \rho)$
Acid Reactor	12,8	
Mesophilic Reactor	(apparent) 372 X	331 ✔

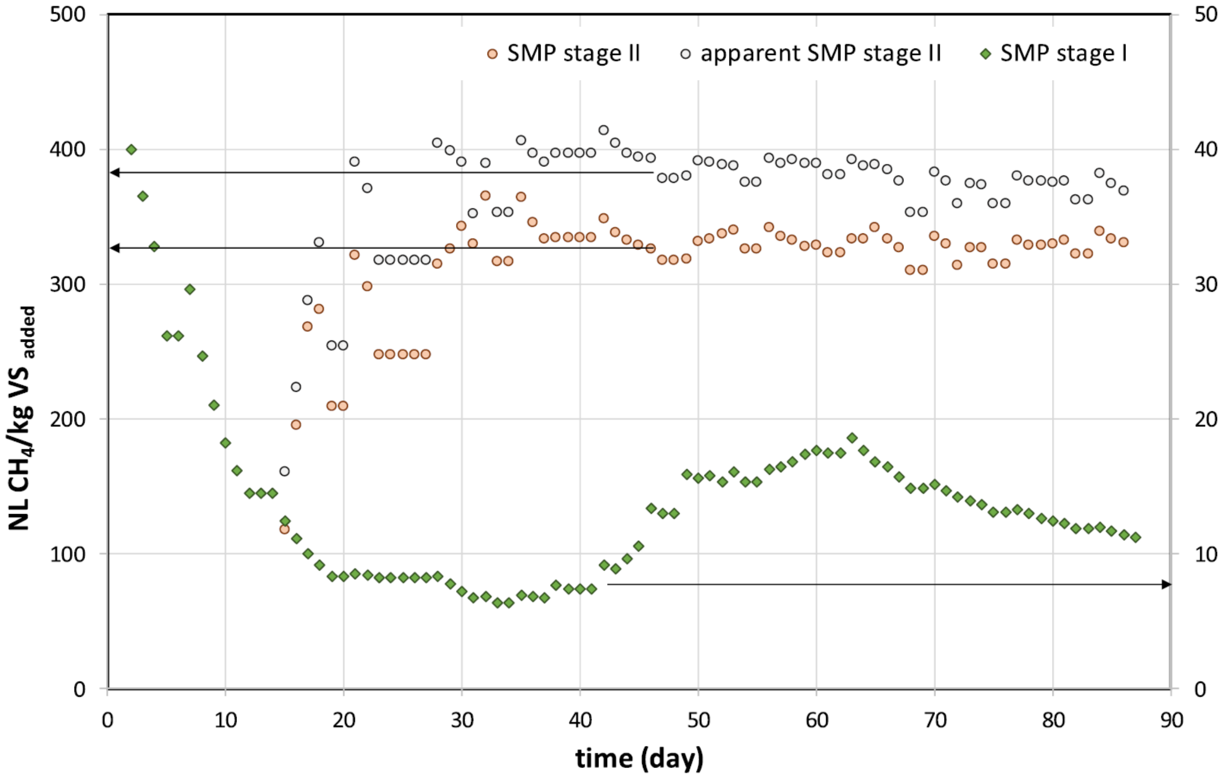
B_0

ρ: $VS_{\text{reduction phase I}} = 11\%$

Results Methane production

ONE-STAGE A.D. HRT 20 days	NL / kg VS
SBP	511,6
SMP	280,6
CH_4	55,0%





TWO-STAGE A.D. HRT 2+20 days	SMP NL / kg VS	$B' = B_0 (1 - \rho)$
Acid Reactor	12,8	
Mesophilic Reactor	(apparent) 372 X	331 ✔

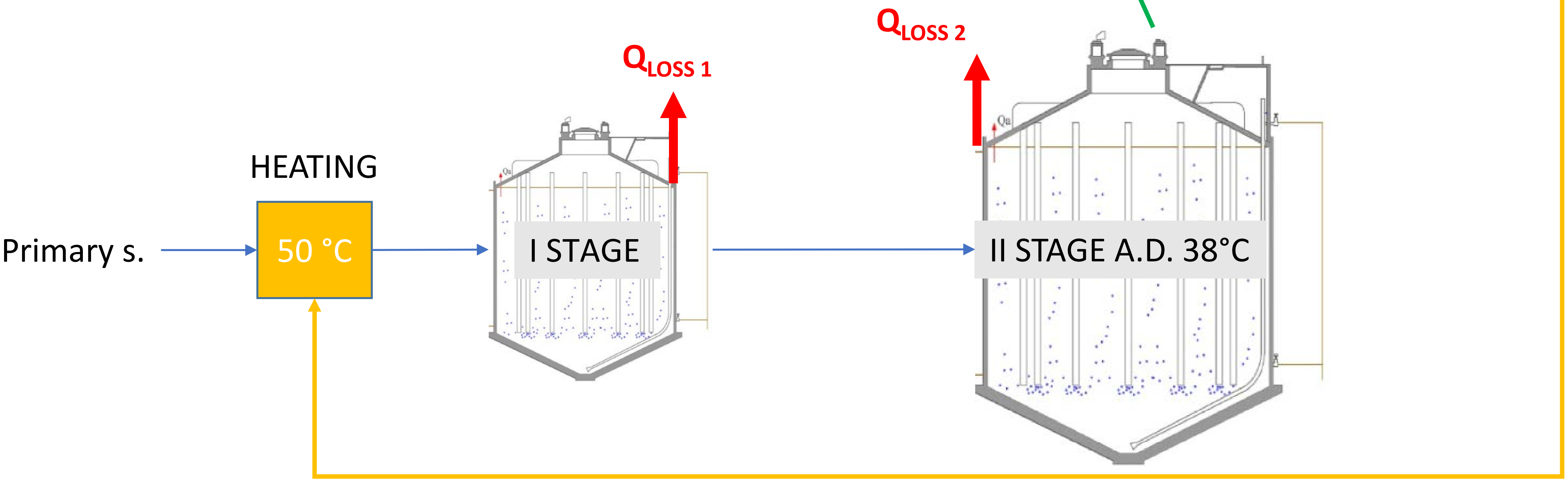
+ 18,6%

Results
Energy assessment
Scenario 1

HYPOTHESIS:
- analysis referred to a unit volumetric flow rate (i.e. 1 m3/h) of P.S.
- TS of the sludge: 4%, VS/TS ratio 0,74
- lower heating value of methane: 35,880 kJ/m3
- boiler efficiency: 0.9
- thermal energy to heat the sludge was calculated by considering a specific heat capacity C: 4.18 kJ/kg/◦C
- ambient temperature: 15°C
- Heat transfer digester walls: 0,8 W/m²/°C
- volume and surface digester → radius to height ratio: 1:1

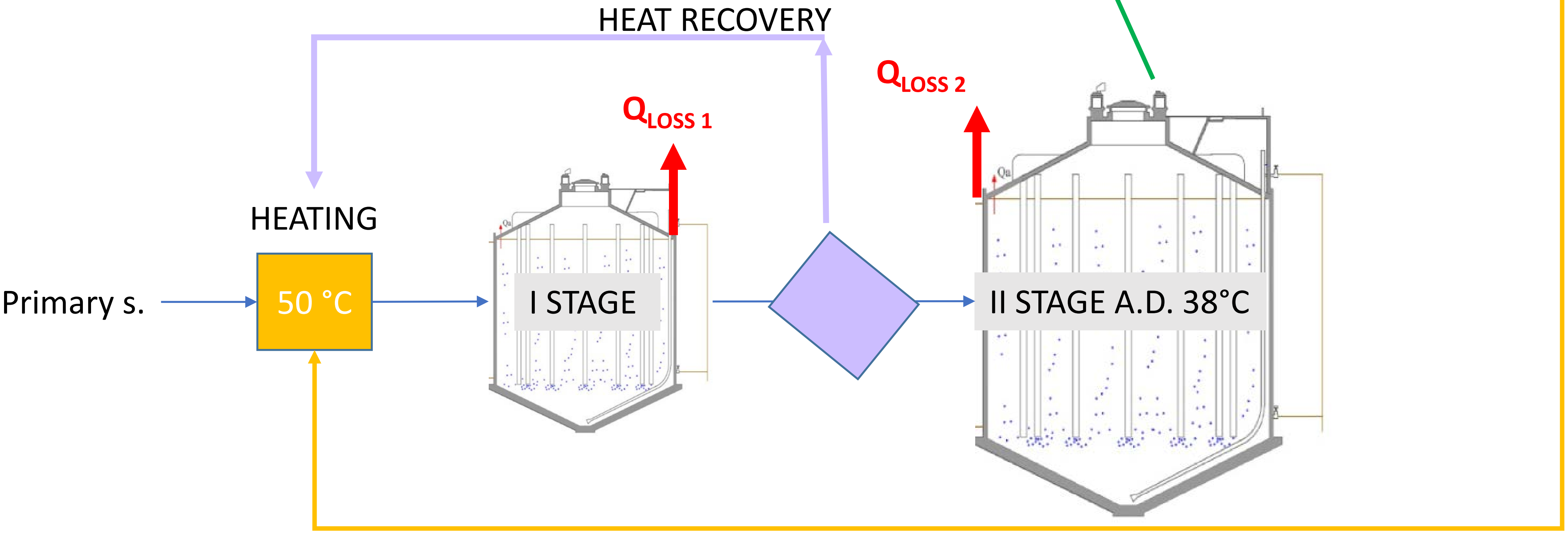
CH_4 network

Boiler

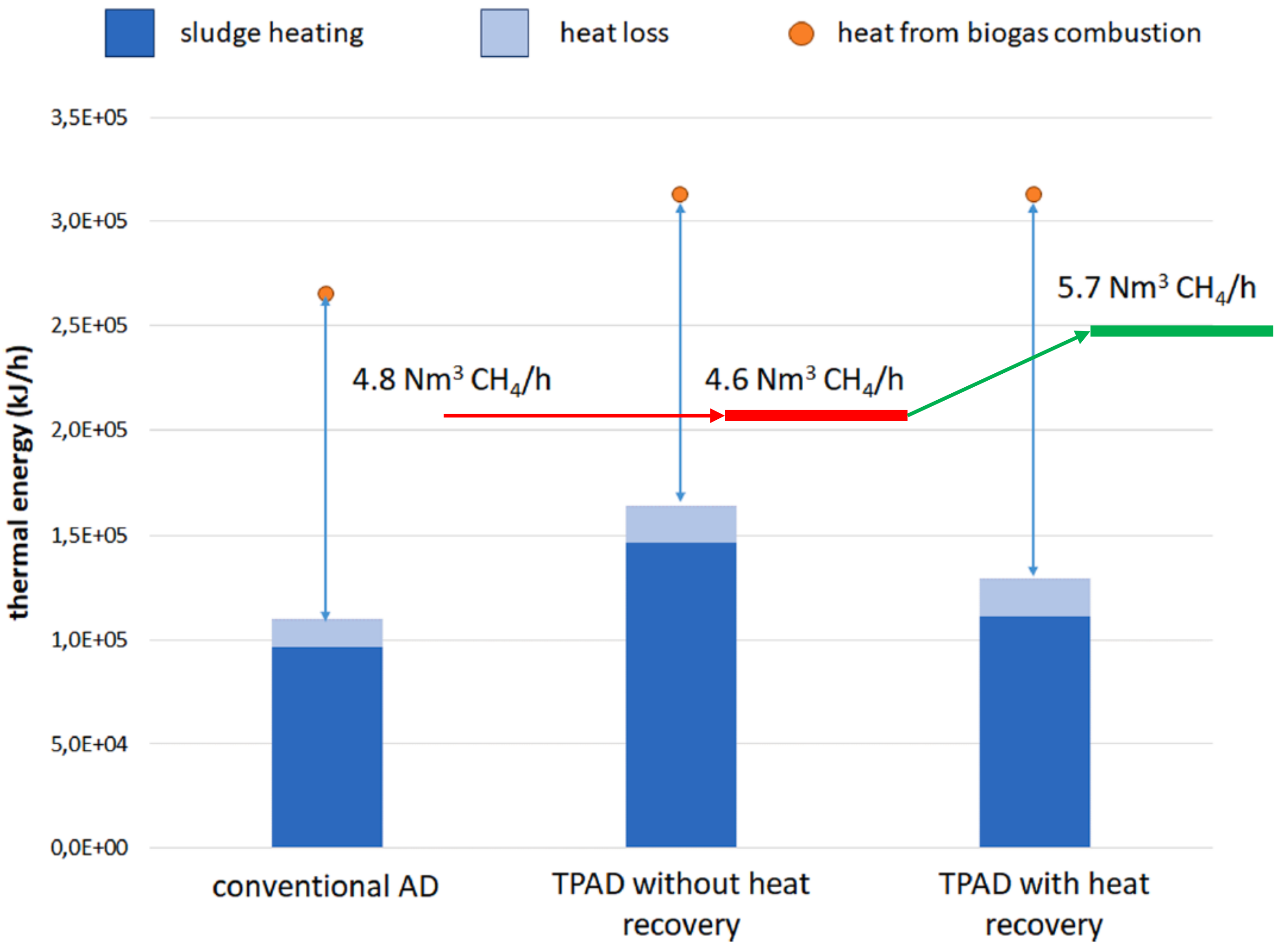


Results
Energy assessment
Scenario 2

HYPOTHESIS:
the difference of temperature between the first (50 ◦C) and the second (38 ◦C) reactor, was recovered with an efficiency estimated at 70% to heat the sludge incoming into the AR.



Results
Energy assessment



+ 19% CH_4 to be transferred to distribution network

SCENARIO I

SCENARIO II

Conclusions

- the TPAD showed a superiority in VS reduction, in fact the overall removal of VS increased from 42.0%, in the one-stage reactor, to 62.2% for the TPAD system with a HRT of 2 days
- the process developed in the two phases of the TPAD was stable for the whole period of the study, as testified by the values of pH and tVFAs/TA ratio;
- the SMP observed in the AR was kept at very low values, in the order of 10–12 NL CH_4/kg VS added, that is approximately 3% of the overall methane production of the TPAD; this was an indication that the status of phase separation between the two acidogenic and methanogenic reactors was successfully achieved;
- the higher SMP observed in the TPAD (+18.6%, with respect to the one-stage digester) was not sufficient to balance the higher heat amounts necessary for sludge heating and heat loss compensation. A process of heat recovery for the sludge between the outlet and the inlet of the AR proved to be necessary to make the TPAD system really profitable;
- the TPAD system, with a section of heat recovery, produced 20% more energy, in the form of methane available for users external to the WWTP, than the traditional digestion system.

For more informations...

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Comparative analysis between a conventional and a temperature-phased anaerobic digestion system: Monitoring of the process, resources transformation and energy balance

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Thermophilic-mesophilic phase
Energy analysis

ABSTRACT

This study was carried out with the principal aim of obtaining reliable outcomes for the future implementation of a temperature-phased anaerobic digestion (TPAD) process in a large (2 M population equivalent, p.e.) WWTP. With the aid of pilot-scale (10 L) reactors fed by pure primary sludge (PS), a TPAD process, where the first and the second reactor were operated at 50 °C and 38 °C, respectively, was compared with a conventional mesophilic (38 °C) anaerobic digestion (AD) process. The initial hydraulic retention time (HRT) of the first, acidogenic, reactor of the TPAD was reduced from 3 to 2 days in the second part of the test.

The results demonstrated that the TPAD system had been stable for all the duration of the test (approx. 100 days), as testified by the steady values of pH and tVFAs/TA ratio, notwithstanding the decrease in the HRT. The TPAD proved to be more efficient in volatile solid (VS) reduction and methane generation, compared to the conventional mesophilic AD process. In fact, the VS reduction increased from 42% to approx. 55% and the specific methane potential (SMP) from 280 to 332 NL/kg VS added. An excellent phase separation was observed between the two acidogenic and methanogenic reactors, as demonstrated by the low SMP (only 3% of the overall production) recorded from the first reactor of the TPAD system.

However, the energy analysis demonstrated that the higher SMP obtained in the TPAD was not sufficient to compensate the higher amounts of heat required for sludge heating and heat loss compensation. Only a process of heat recovery could make the TPAD system really profitable, thus increasing the aliquot of energy in the form of methane, available for users external to the WWTP, by 20%. This result represents a step in the evolution of traditional WWTPs towards more energy efficient and sustainable facilities.

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Thank you for your attention!

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