UNIVERSITY OF Southampton
School of Civil Engineering and the Environment

VALORGAS

Microbiology of food waste digestion & effects of trace element additions

Charles Banks

ADSW&EC 2011 Vienna, Austria
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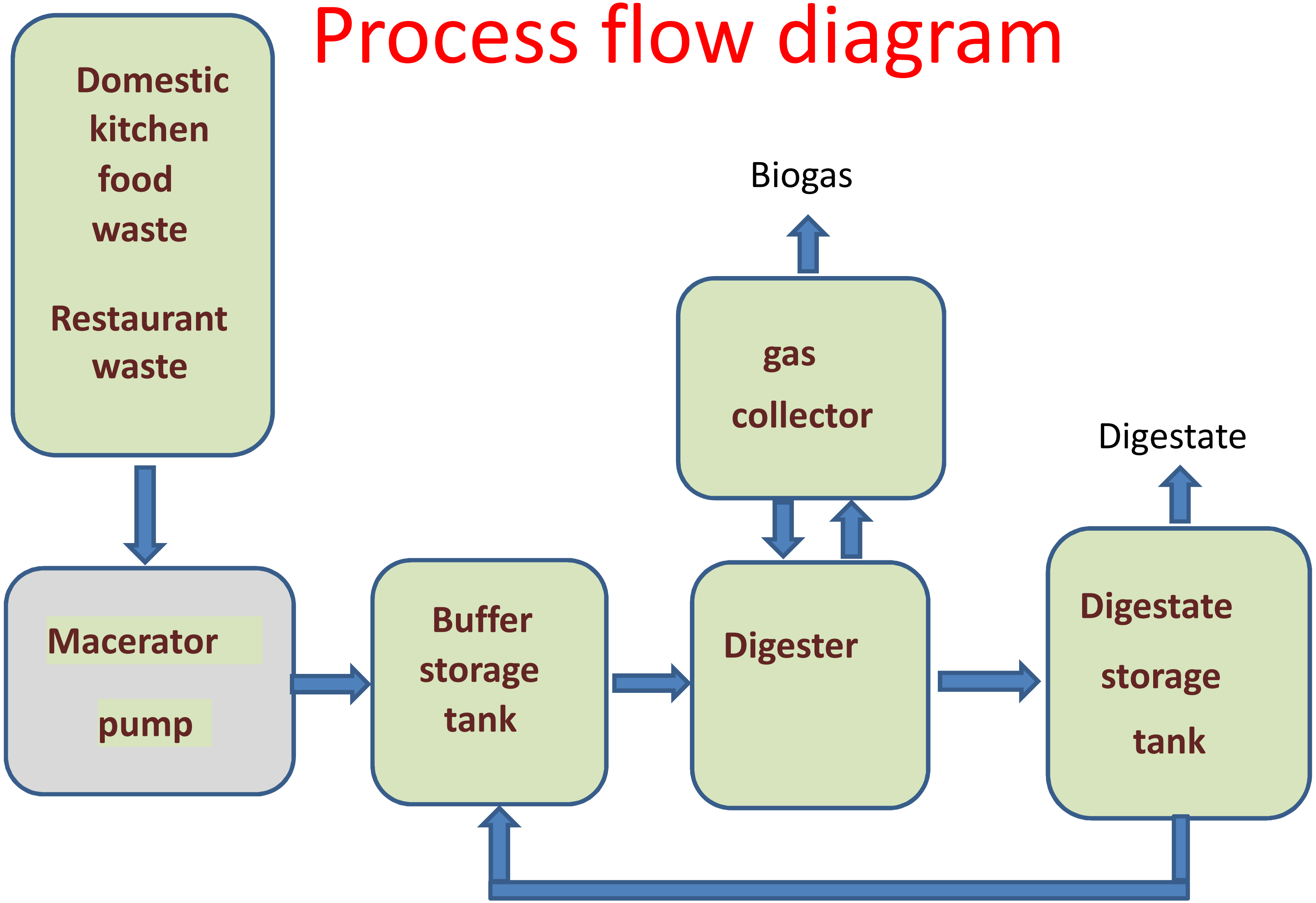
International Water Association

Collected food waste

Food waste preparation

Commercial garbage grinder – no water added

Process flow diagram



Digesters used early study

SURVIVAL OF *SALMONELLA* IN THE ANAEROBIC DIGESTION OF KITCHEN WASTE

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SUMMARY: The research considered whether the anaerobic digestion of kitchen waste would sanitise the material to an extent where the digestate would be suitable for spreading on arable land, or whether a pasteurisation stage would also be required. Two pilot-scale anaerobic digesters were operated: one at 36.5°C, the other at 56°C. High concentrations of pathogenic bacteria were found in the collected food waste samples, with an average of 121 MPN g^{-1} *Salmonella*. The number of *Salmonella* was significantly reduced in the mesophilic digester and, after the introduction of hygiene measures to prevent bypass, it was generally absent in the thermophilic digester. The results are discussed in relation to changes in pH, volatile fatty acids and temperature during the digestion process. The requirement for pasteurisation of the mesophilic and thermophilic digestate prior to spreading on arable land is presented in view of recent changes to European regulations.

Biodigestion of kitchen waste

A comparative evaluation of mesophilic and thermophilic biodigestion for the stabilisation and sanitisation of kitchen waste

Final report prepared by

The University of Southampton and Greenfinch Ltd

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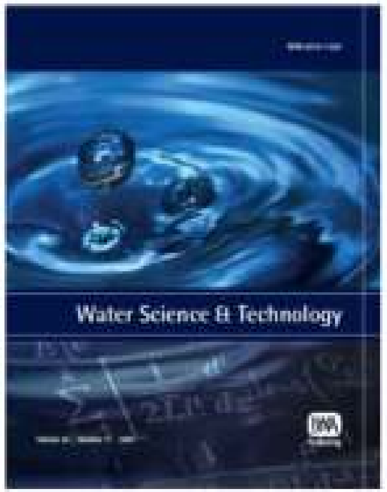
A pilot-scale comparison of mesophilic and thermophilic digestion of source segregated domestic food waste

Charles J. Banks, Michael Chesshire and Anne Stringfellow

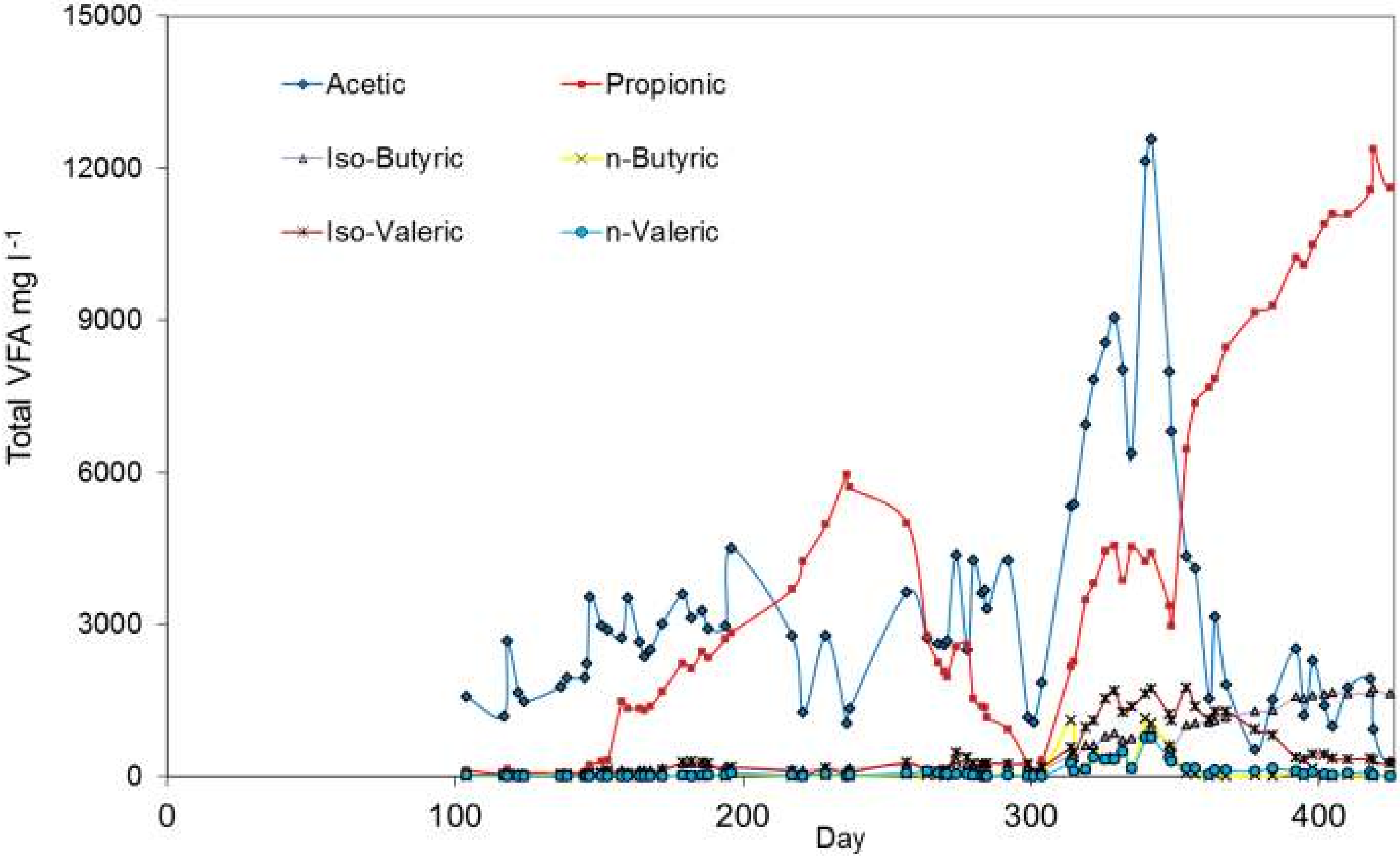
ABSTRACT

Source segregated food waste was collected from domestic properties and its composition determined together with the average weight produced per household, which was 2.91 kg per week. The waste was fed over a trial period lasting 58 weeks to an identical pair of 1.5 m^3 anaerobic digesters, one at a mesophilic (36.5°C) and the other at a thermophilic temperature (56°C). The digesters were monitored daily for gas production, solids destruction and regularly for digestate characteristics including alkalinity, pH, volatile fatty acid (VFA) and ammonia concentrations. Both digesters showed high VFA and ammonia concentrations but in the mesophilic digester the pH remained stable at around 7.4, buffered by a high alkalinity of 13,000 mg l^{-1}; whereas in the thermophilic digester VFA levels reached 45,000 mg l^{-1} causing a drop in pH and digester instability. In the mesophilic digester volatile solids (VS) destruction and specific gas yield were favourable, with 67% of the organic solids being converted to biogas at a methane content of 58% giving a biogas yield of 0.63 m^3 kg^{-1} VS_{added}. Digestion under thermophilic conditions showed potentially better VS destruction at 70% VS and a biogas yield of 0.67 m^3 kg^{-1} VS_{added}, but the shifts in alkalinity and the high VFA concentrations required a reduced loading to be applied. The maximum beneficial loading that could be achieved in the mesophilic digester was 4.0 kg VS m^{-3} d^{-1}.

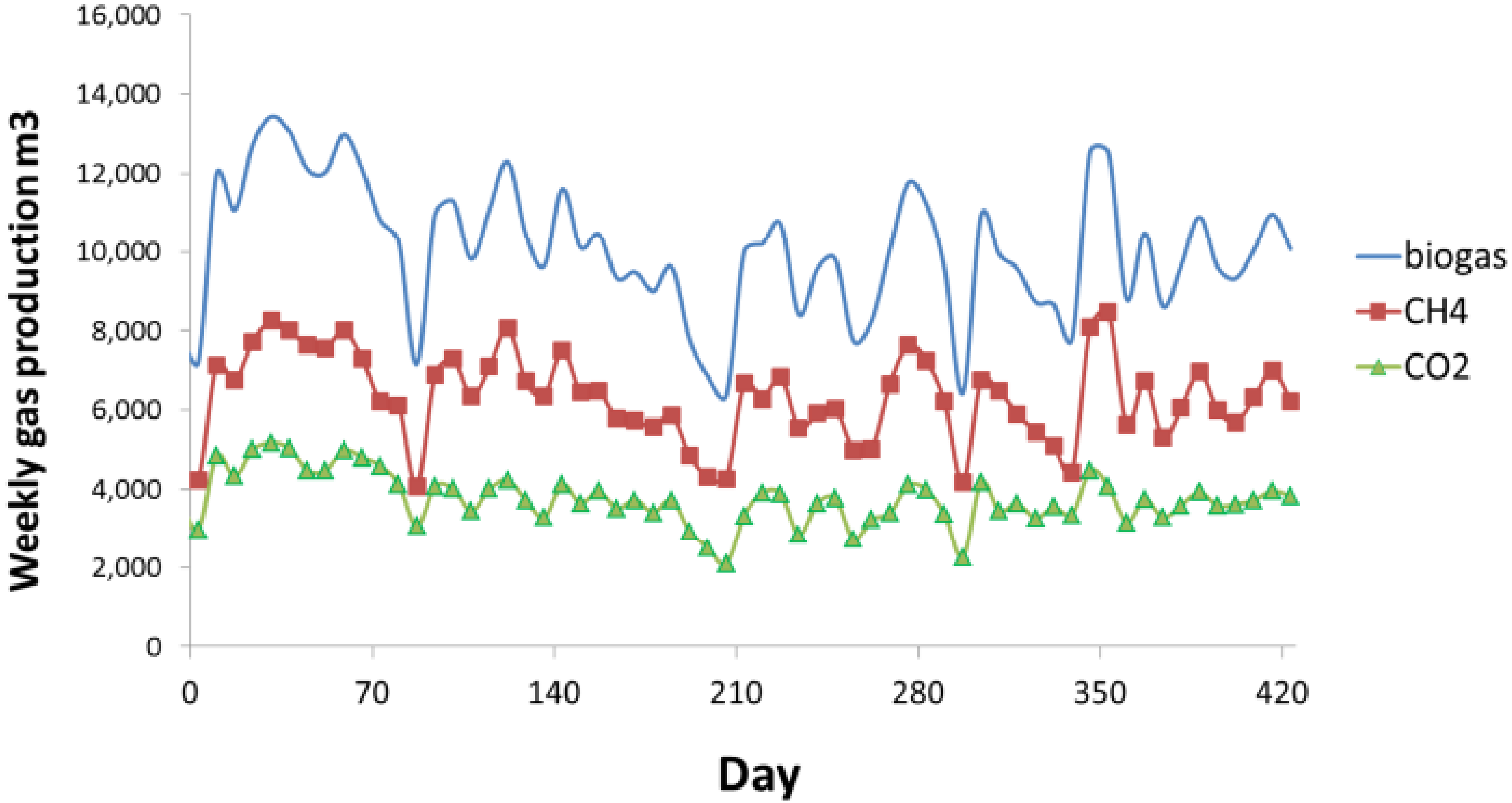
Key words | food waste, kitchen waste, mesophilic, thermophilic, volatile fatty acids



Demonstration plant



Acetic
Propionic
Iso-Butyric
n-Butyric
Iso-Valeric
n-Valeric
15000
12000
9000
6000
3000
0
Total VFA mg l-1
0
100
200
300
400
Day



16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
Weekly gas production m3
0
70
140
210
280
350
420
Day
biogas
CH4
CO2

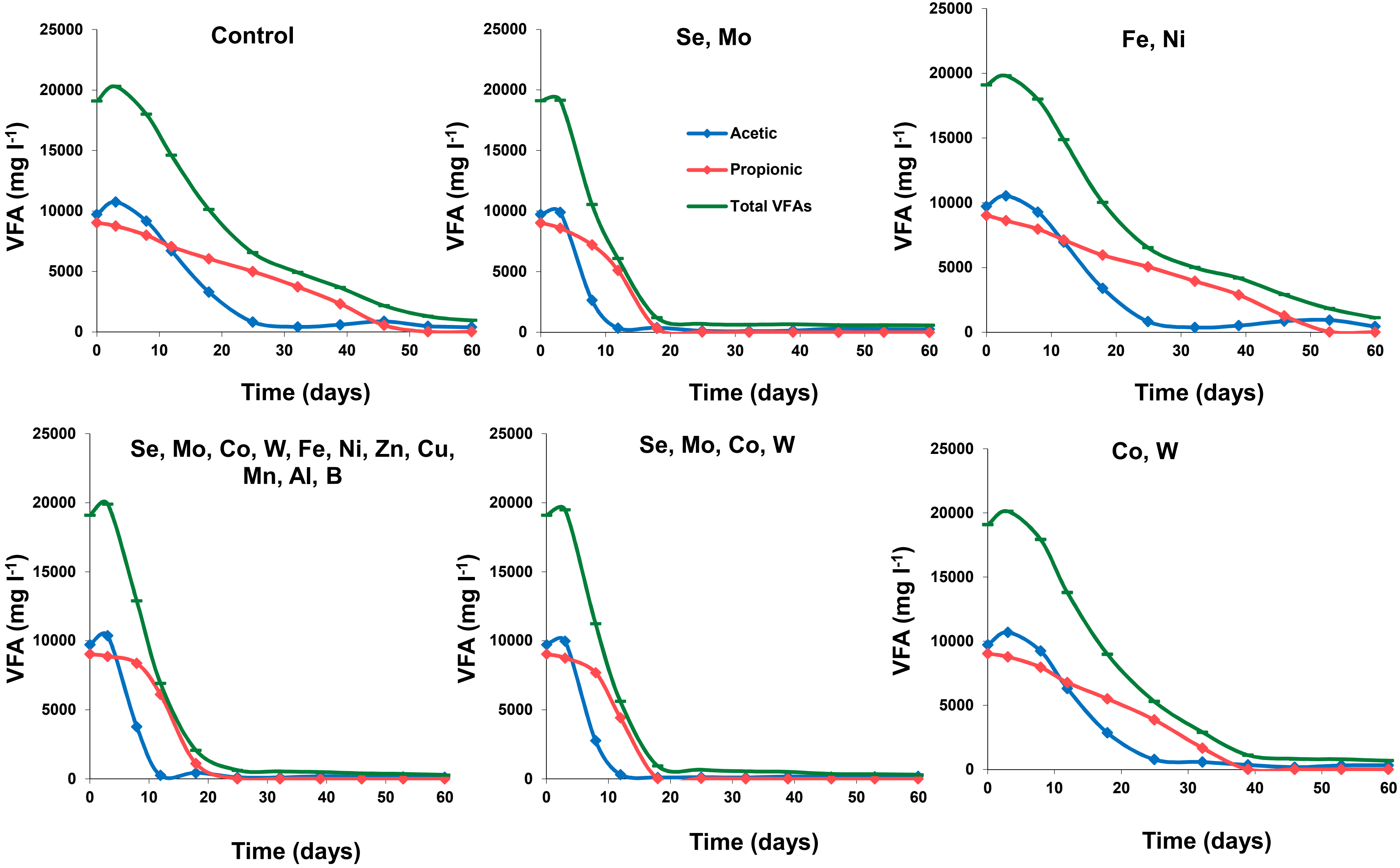
Facts, speculation and interpretation

Accumulation of VFA after extended period of time	→	Something accumulating? Something depleted?
Acetic acid peak replaced by propionic acid peak	→	Loss of acetoclastic methanogens could lead to acetic acid peak
Accumulation of ammonia	→	Ammonia known to be toxic to acetoclastic methanogens
Can carbon flow to methane in the absence of acetoclastic methanogens?	→	Could have methane production from hydrogen and carbon dioxide (hydrogenotrophic route)
Why does propionic acid accumulate?	→	Uneven carbon chain length – breaks down to acetic and formic acids
What is the significance of formic acid?	→	Accumulation of formic acid will stop further breakdown of propionic acid
Formic acid can only be used by hydrogenotrophic methanogens	→	Is there a special enzyme system needed?
Selenium and Tungsten possibly essential trace elements for formate reductase enzyme system	→	Are these commonly added in trace element formulations? What is the concentration in food waste?
Can we prove the theory	→	Will need to look at combination of TE trials, metabolic assays and serotyping

Fractional factorial design

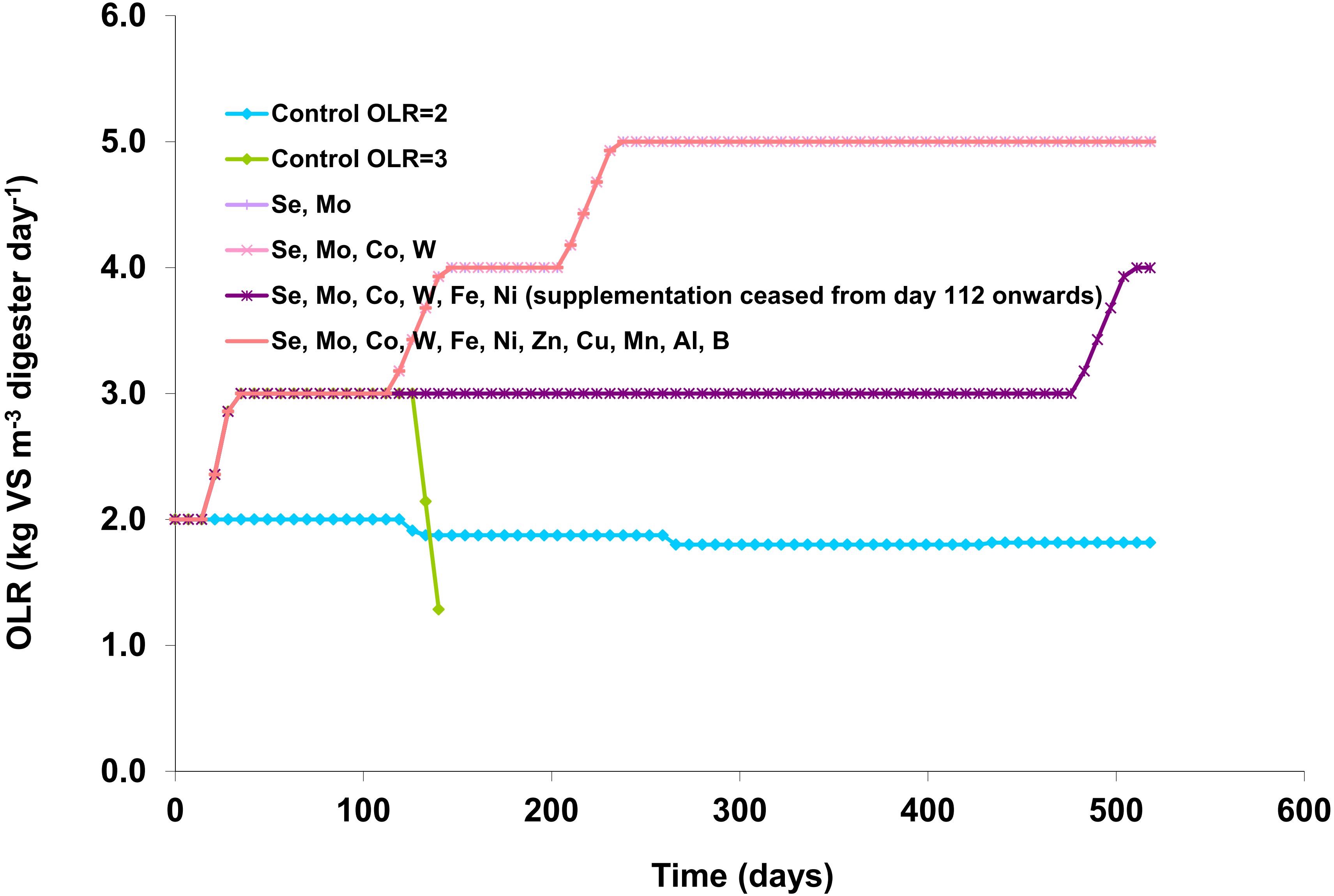
Run	Pattern	Co	Ni	Mo	Se	Fe	W	Zn	Cu	Mn	Al	B
1	−−−−−−−−−−−	-	-	-	-	-	-	-	-	-	-	-
2	−−−+++−−−−−	-	-	-	Se	Fe	W	-	-	-	-	-
3	−−+−++−−−−−	-	-	Mo	-	Fe	W	-	-	-	-	-
4	−−++−−−−−−−	-	-	Mo	Se	-	-	-	-	-	-	-
5	−+−−+−−−−−−	-	Ni	-	-	Fe	-	-	-	-	-	-
6	−+−+−+−−−−−	-	Ni	-	Se	-	W	-	-	-	-	-
7	−++−−+−−−−−	-	Ni	Mo	-	-	W	-	-	-	-	-
8	−++++−−−−−−	-	Ni	Mo	Se	Fe	-	-	-	-	-	-
9	+−−−−+−−−−−	Co	-	-	-	-	W	-	-	-	-	-
10	+−−++−−−−−−	Co	-	-	Se	Fe	-	-	-	-	-	-
11	+−+−+−−−−−−	Co	-	Mo	-	Fe	-	-	-	-	-	-
12	+−++−+−−−−−	Co	-	Mo	Se	-	W	-	-	-	-	-
13	++−−++−−−−−	Co	Ni	-	-	Fe	W	-	-	-	-	-
14	++−+−−−−−−−	Co	Ni	-	Se	-	-	-	-	-	-	-
15	+++−−−−−−−−	Co	Ni	Mo	-	-	-	-	-	-	-	-
16	++++++−−−−−	Co	Ni	Mo	Se	Fe	W	-	-	-	-	-
17	+++++++−−−−	Co	Ni	Mo	Se	Fe	W	Zn	-	-	-	-
18	+++++++++−−	Co	Ni	Mo	Se	Fe	W	Zn	Cu	Mn	-	-
19	+++++++++++	Co	Ni	Mo	Se	Fe	W	Zn	Cu	Mn	Al	B

Acetic and Propionic acids degradation profiles

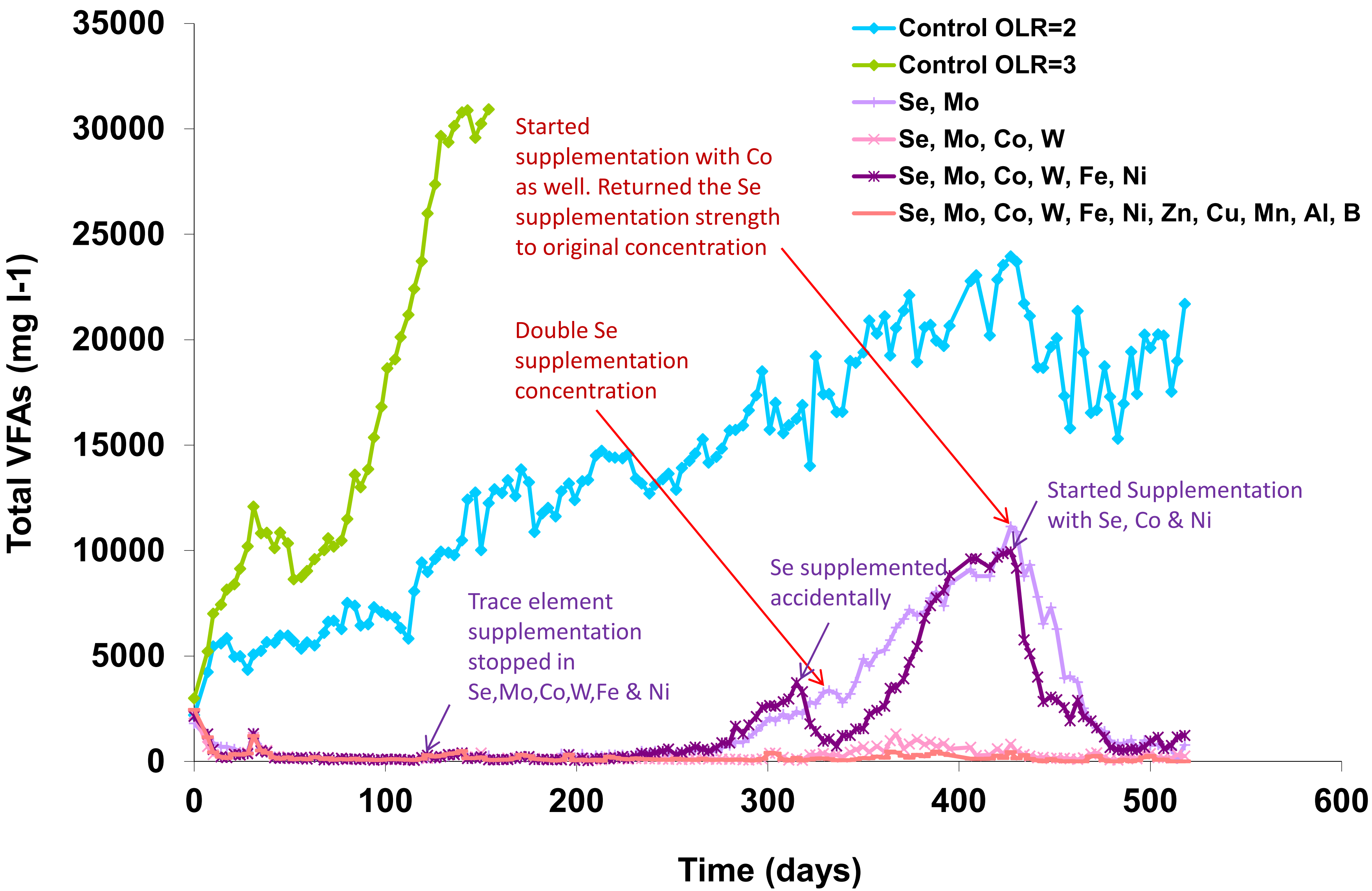


75-litre digesters

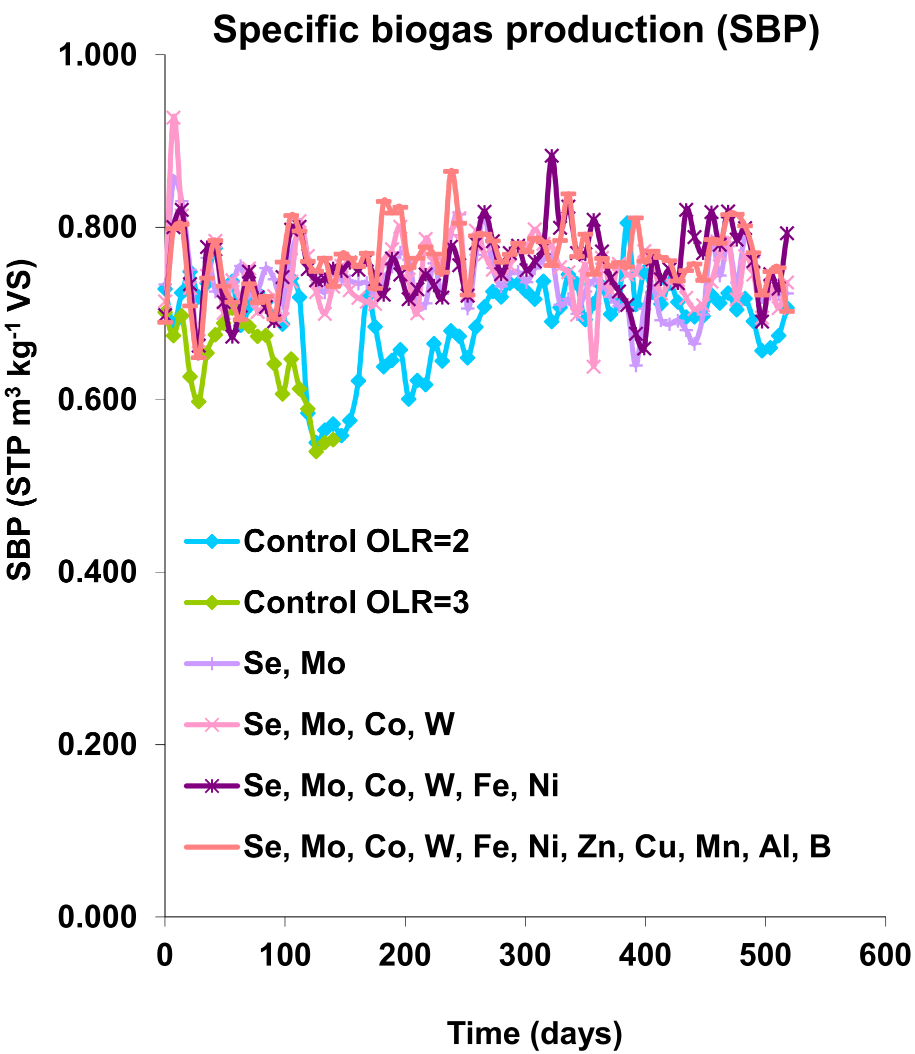
Organic loading rate (OLR)

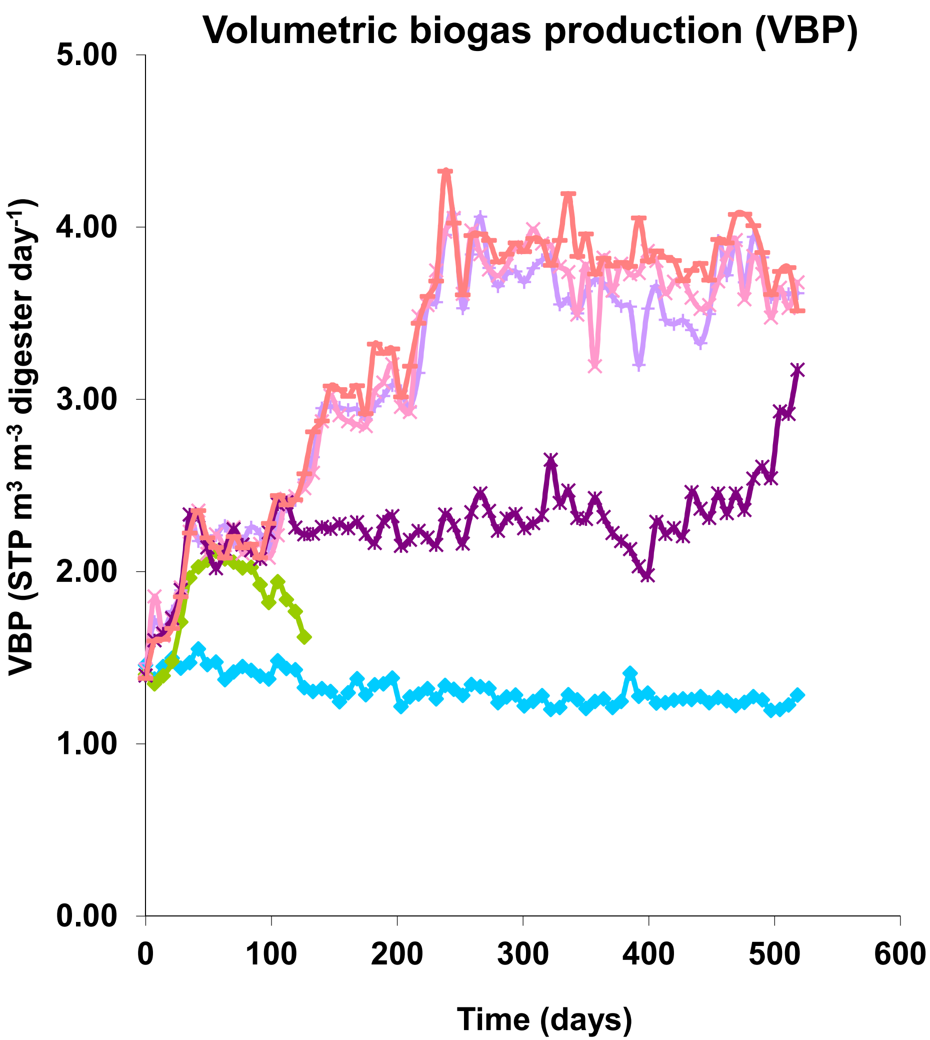


Volatile fatty acids profiles

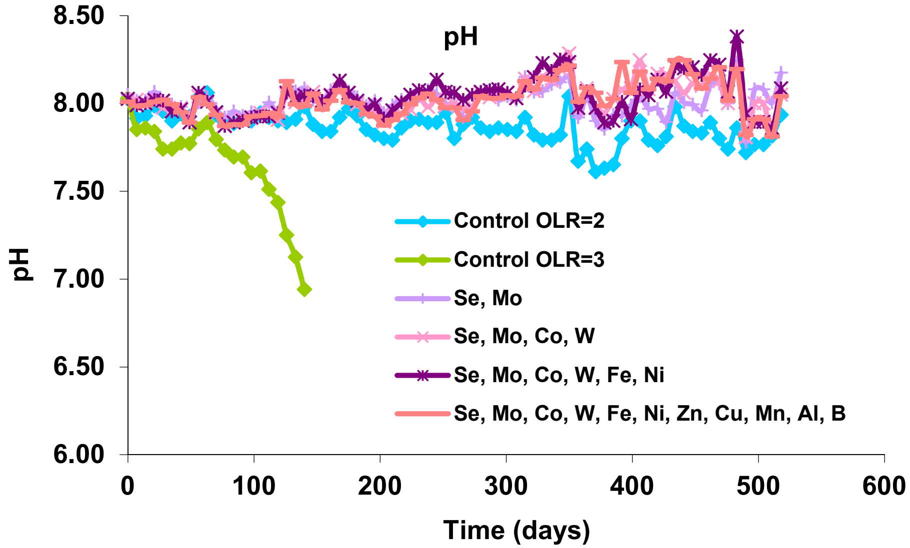


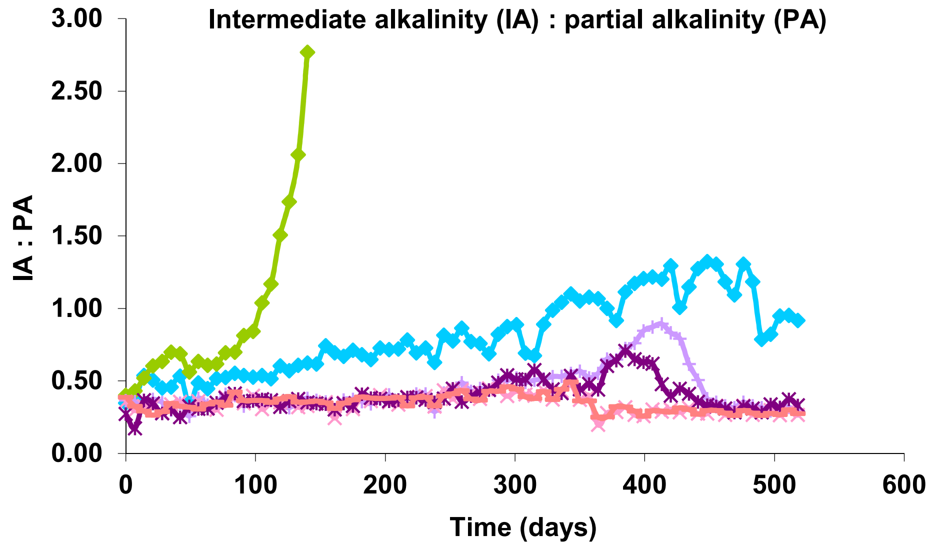
Digestion efficiency

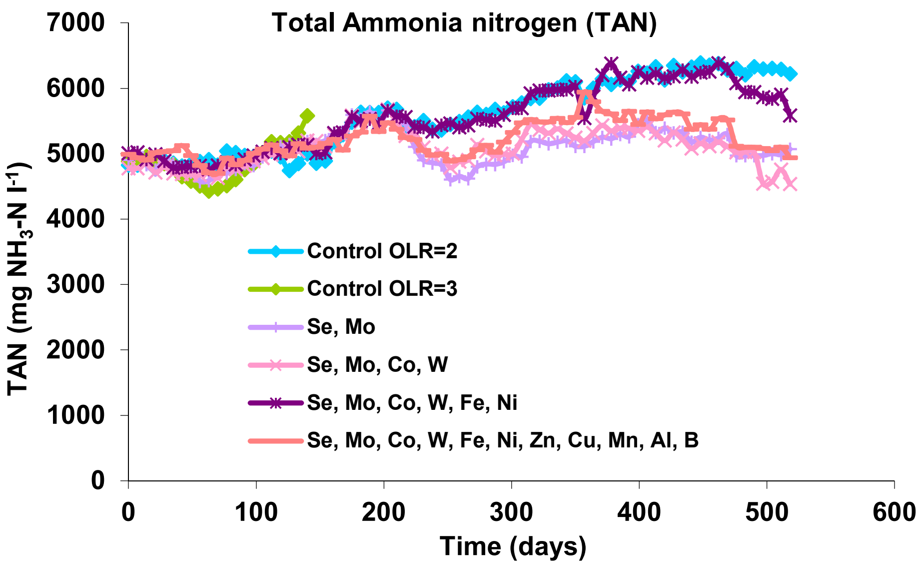


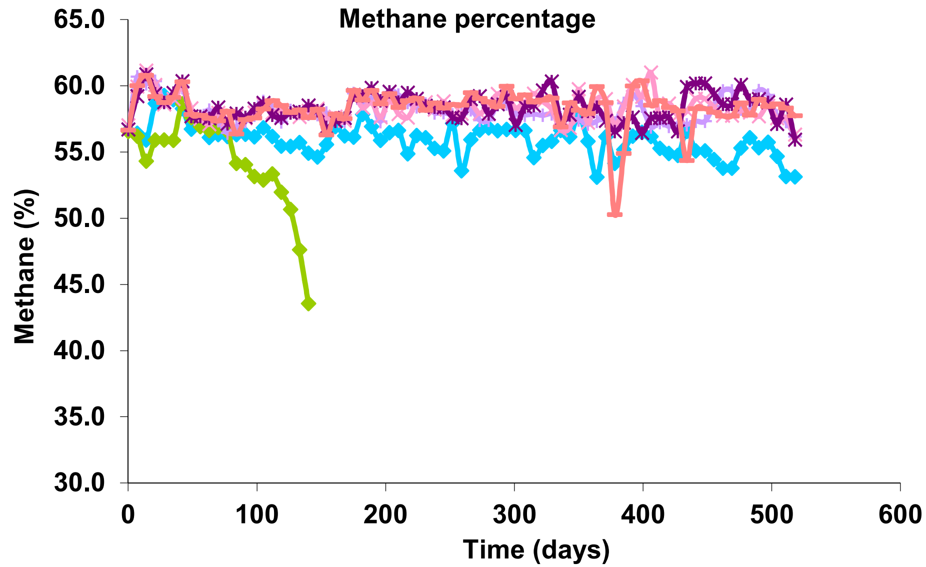


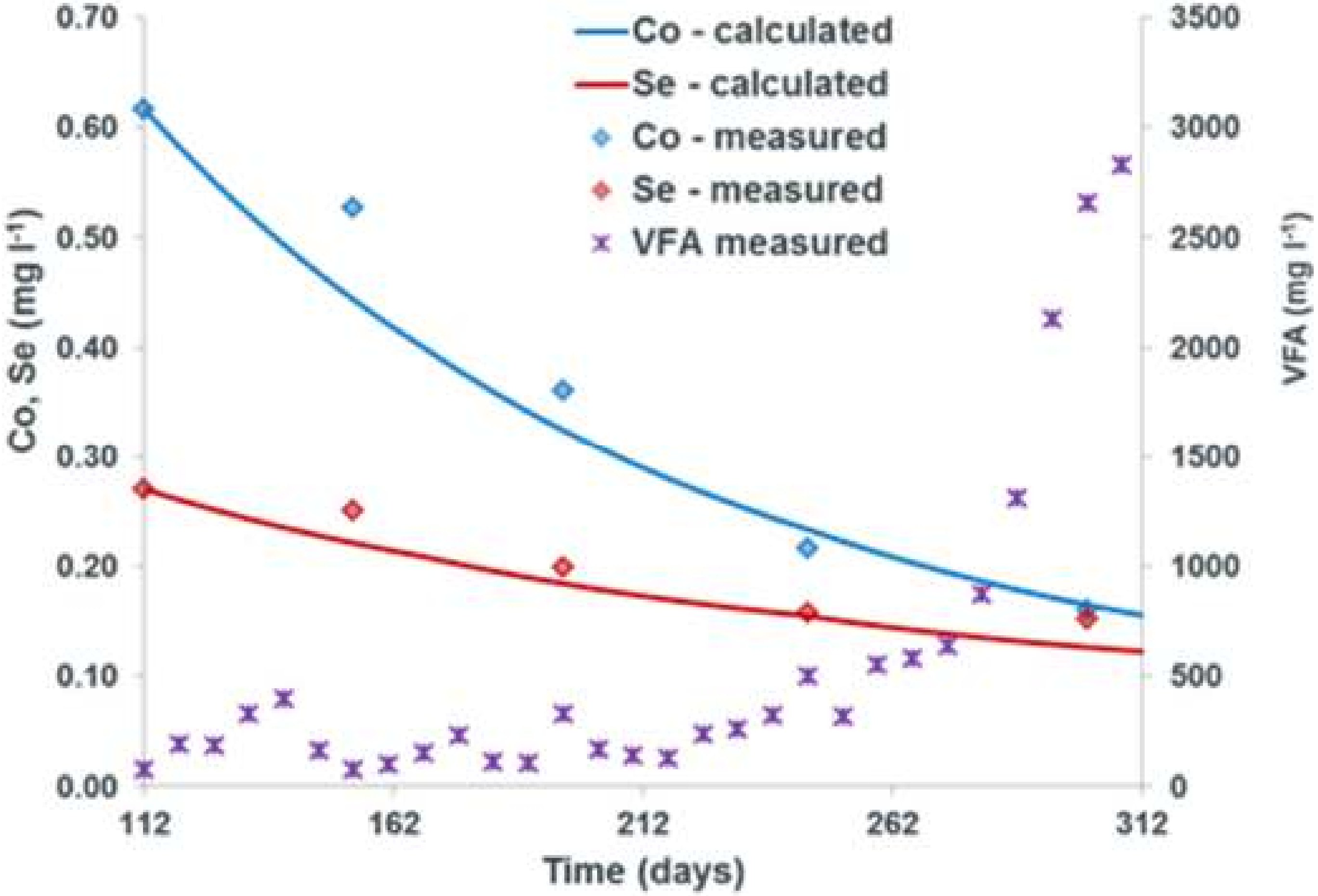
Other digester parameters











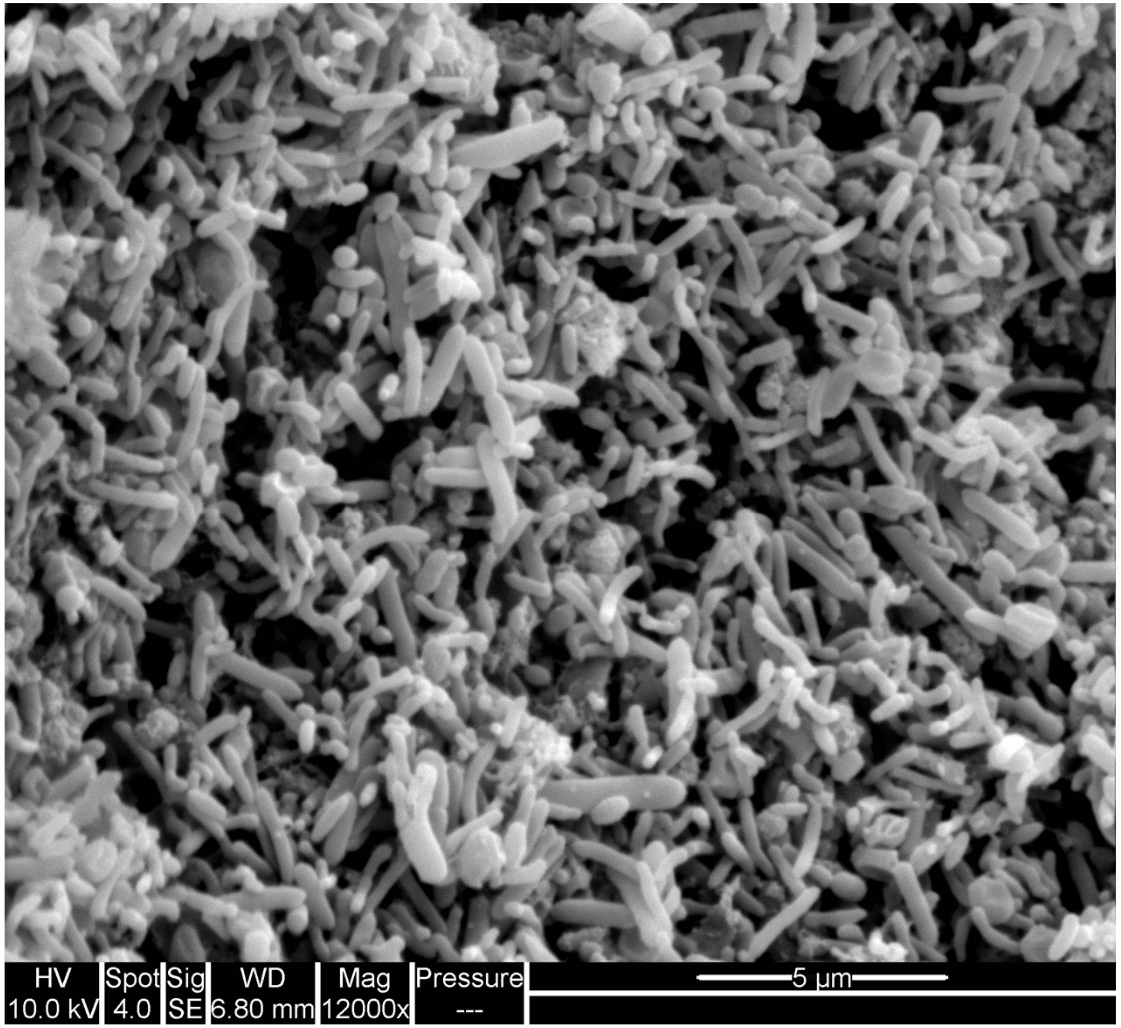
Trace element washout – estimating the critical dose

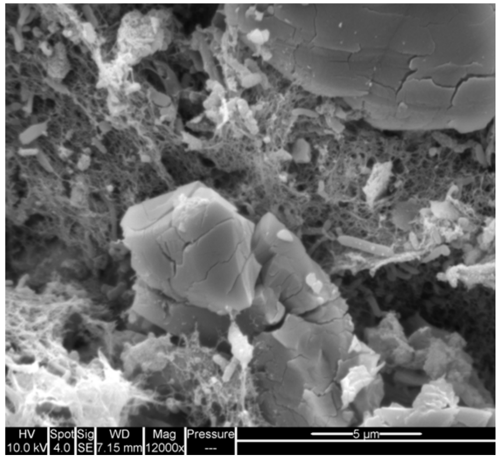
TE required *vs* TE in the food waste

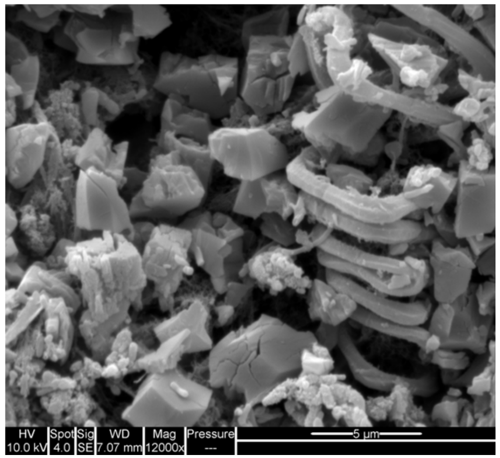
	Minimum requirement at a moderate loading rate	Hackney, London	Luton, South Bedfordshire	Ludlow, Shropshire
Co	0.22	0.090±0.049	0.017±0.002	<0.060
Se	0.16	0.10±0.08	0.28±0.14	<0.07
TKN	-	8100	7400	8100

Unit: mg kg^{-1}
fresh matter

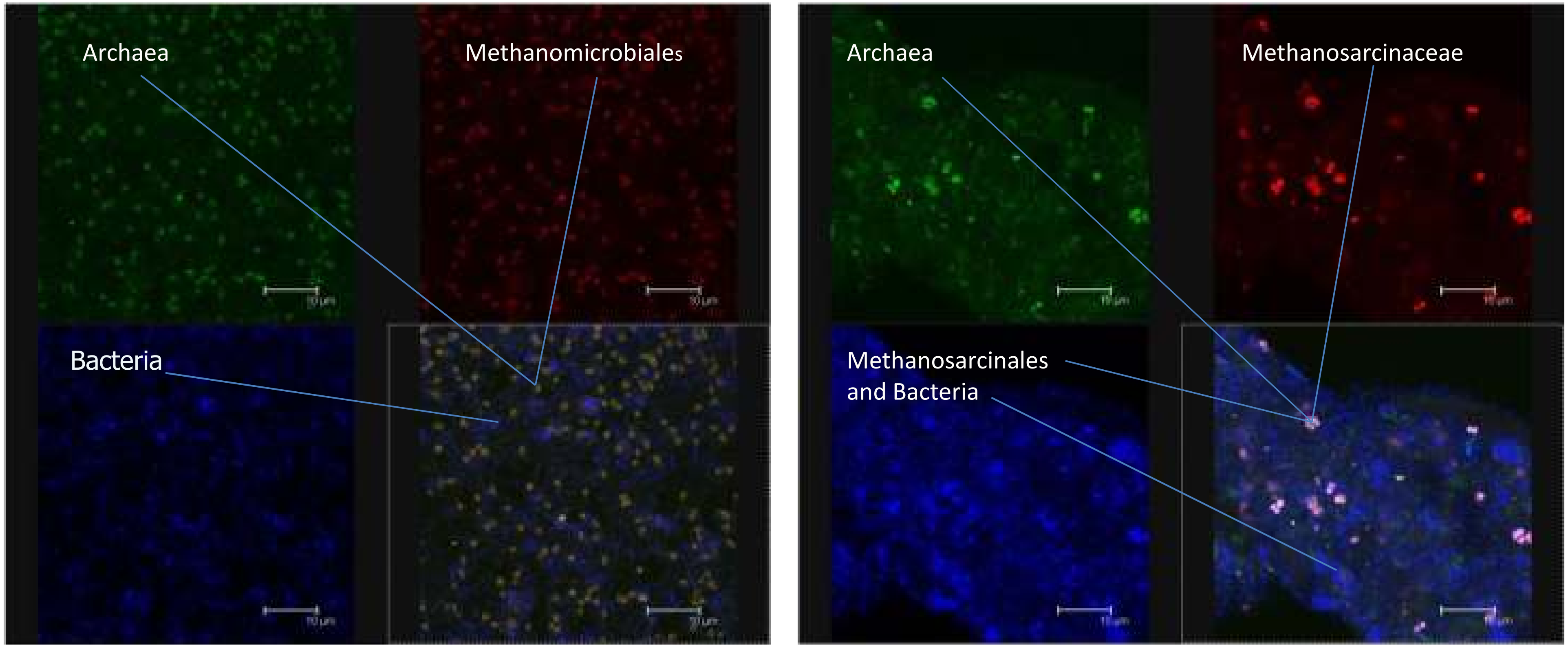
Density gradient centrifugation – SEM images







FISH images



***Methanomicrobiales* (food waste digestion)** ***Methanosarcinaceae* (vegetable waste digestion)**

Probe name	Target group	Probe sequence (5'-3')	Fluorescent dye	Fluorescent colour	Formamide (%)
EUB338	*Bacteria*	GCTGCCTCCCGTAGGAGT	Cy5	blue	20~50
ARC915	*Archaea*	GTGCTCCCCCGCCAATTCCT	6-Fam	green	20~50
MG1200	*Methanomicrobiales*	CGGATAATTCGGGGCATGCTG	Cy3	red	20
MS1414	*Methanosarcinaceae*	CTCACCCATACCTCACTCGGG	Cy3	red	50
MSMX860	*Methanosarcinales*	GGCTCGCTTCACGGCTTCCCT	Cy5	blue	45

Conclusions (trace elements)

- Selenium and cobalt are the key trace elements needed for the long-term stability of food waste digesters, but are likely to be lacking in the food waste
- The minimum concentrations recommended in food waste digesters for selenium, cobalt are around 0.16, 0.22 mg l^{-1} respectively, when running at a moderate organic loading rate
- A total selenium concentration greater than 1.5 mg l^{-1} is likely to be toxic to the microbial consortium in the digester
- Food waste is likely to have sufficient Al, B, Cu, Fe, Mn, and Zn. We are still not sure about Ni, Mo and W

Conclusions (Digester operation)

- Following proper trace element supplementation strategy, food waste digesters can be operated stably with low VFA concentrations at an organic loading rate of 5 kg VS m^{-3} d^{-1} with a volumetric biogas production of 3.8 STP m^{3} m^{-3} d^{-1} and specific biogas production of 0.76 STP m^{3} kg^{-1} VS
- Prevention of VFA accumulation in the digester by trace element supplementation is necessary, as recovery of a severely VFA-laden digester is not a rapid process even when supplements are added

Commercial scale

Thanks to DEFRA WR1208

Dr Yue Zhang, Biogen-Greenfinch

…and to EU FP7 VALORGAS for continuing support to take this work forward