

UNIVERSITY OF
Southampton
School of Civil Engineering
and the Environment

Charles Banks

IEA Task 37, Tubitak MRC, April 14th 2011

Matching AD requirements to different feedstocks

Understanding the process and its
requirements: a case study of food waste
digestion in the UK

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Why digest food waste?

- Animal and public health prevents us feeding this to animals
- EU Landfill Directive requires diversion of biodegradable waste
- Food waste between 20 – 30% of kerbside collected material
- Removes wet and putrescible waste and makes recycling of dry wastes easier
- Biofertiliser from digestion is free of contaminants and can be applied to agricultural land
- Keeps the process simple

Composition of household collected kitchen waste

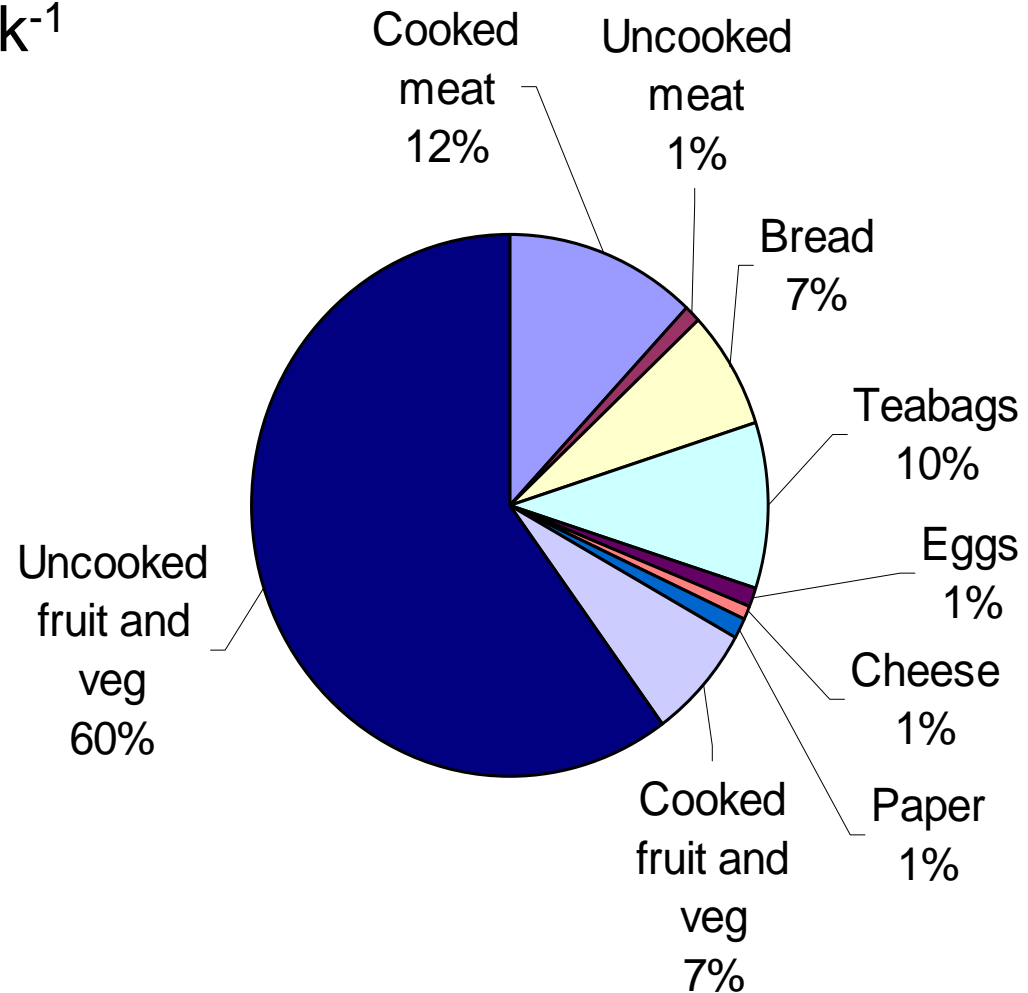
2.91 kg household⁻¹ week⁻¹

TS = 23%

VS = 93% of TS

$C_{252}H_{39}O_{132}N_{18}S_1$

C : N ratio 14:1

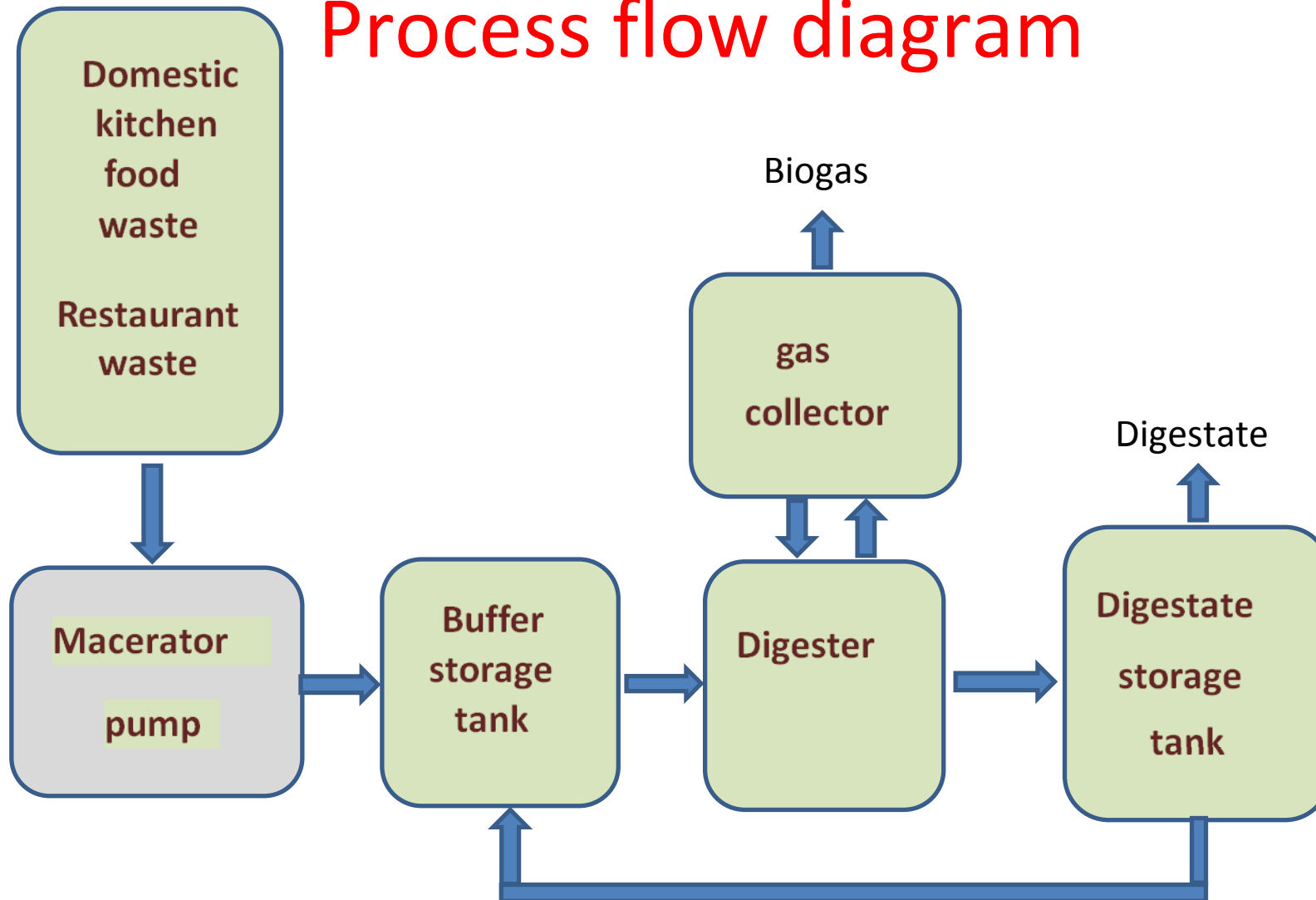


Collected food waste





Process flow diagram



Digesters used early study

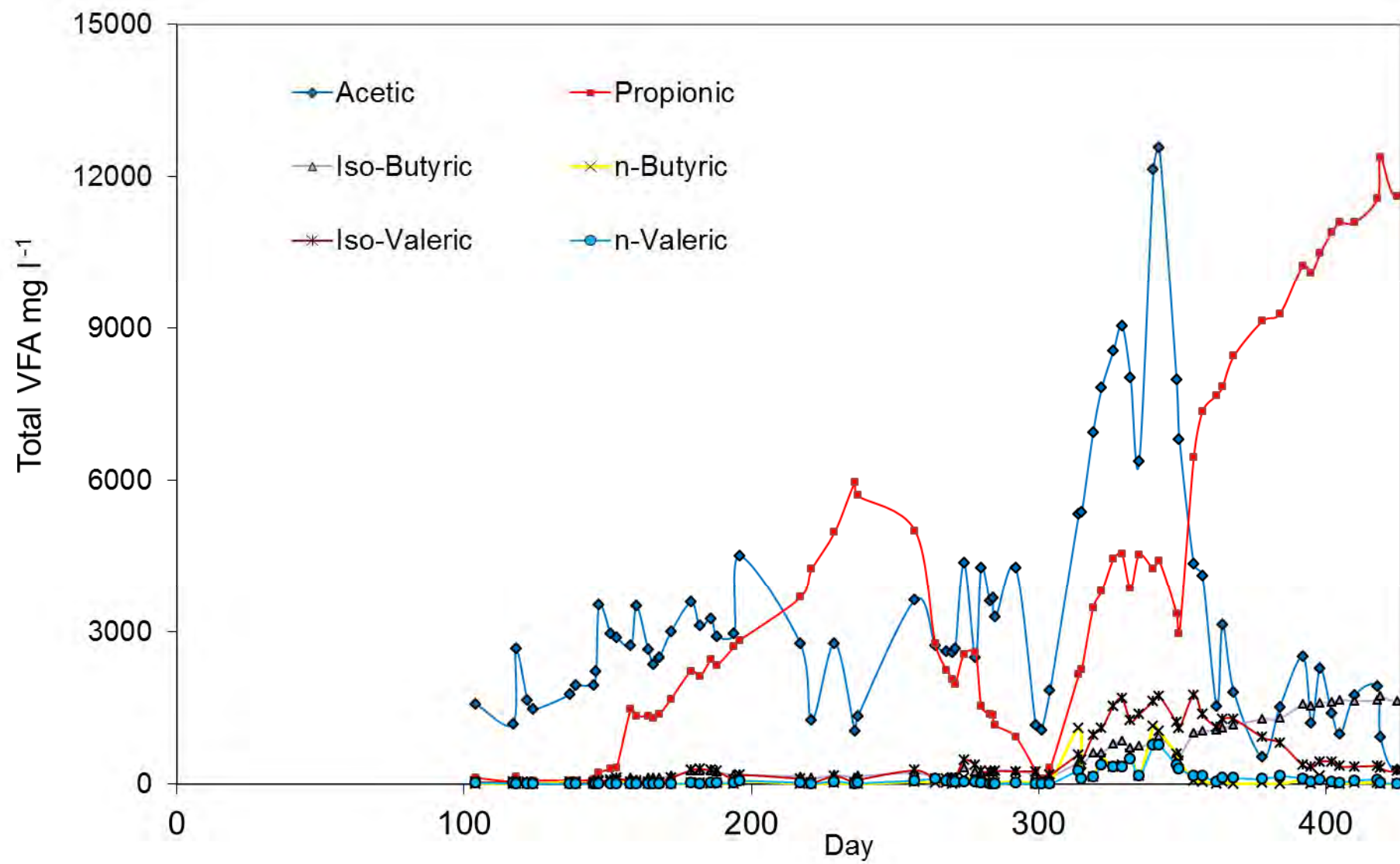


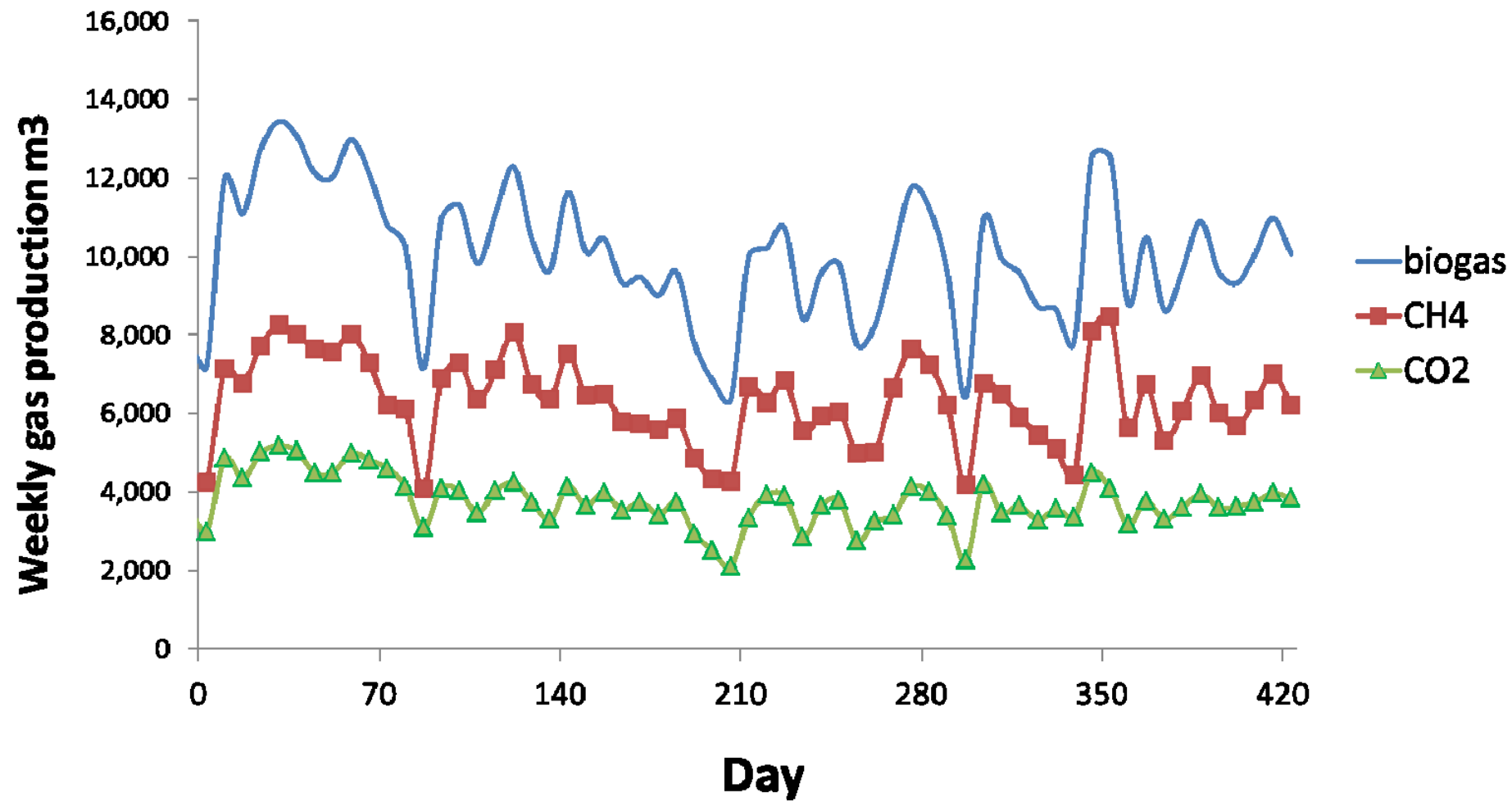
Demonstration plant



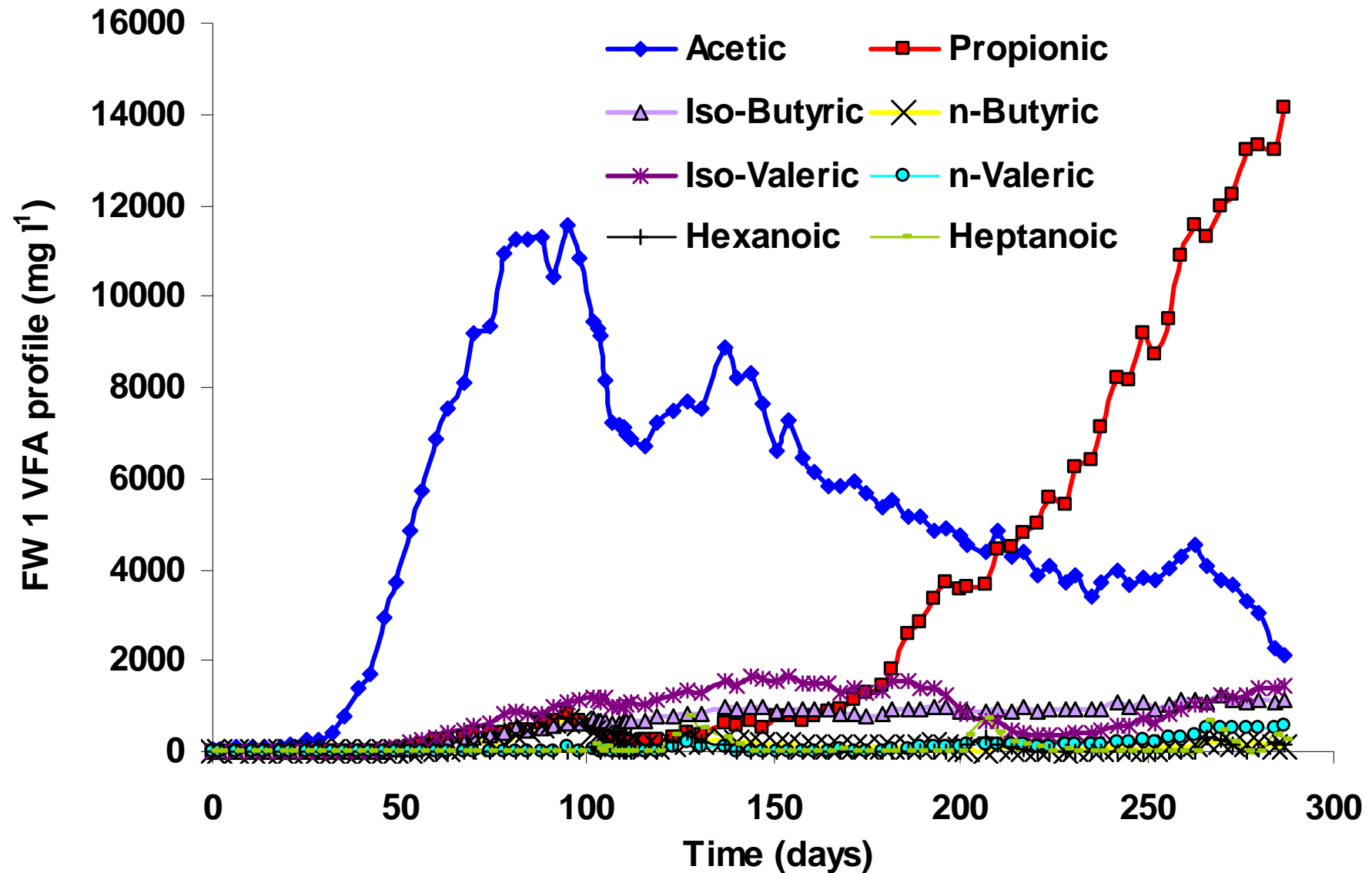
Full scale plant



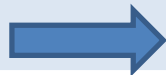


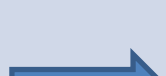


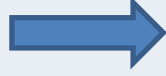

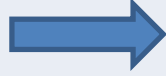




VFA in 35-litre FW digester



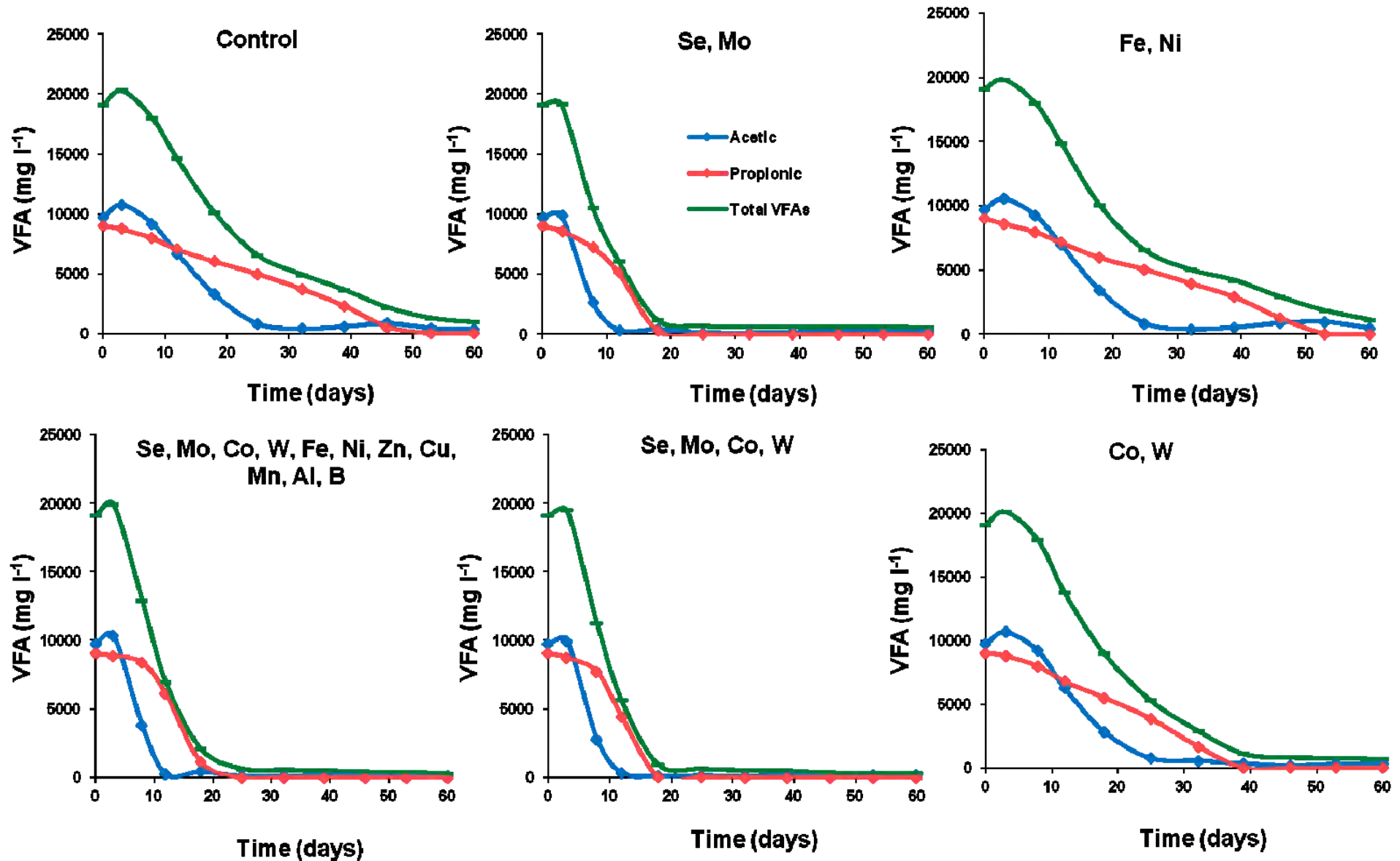
Facts, speculation and interpretation

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

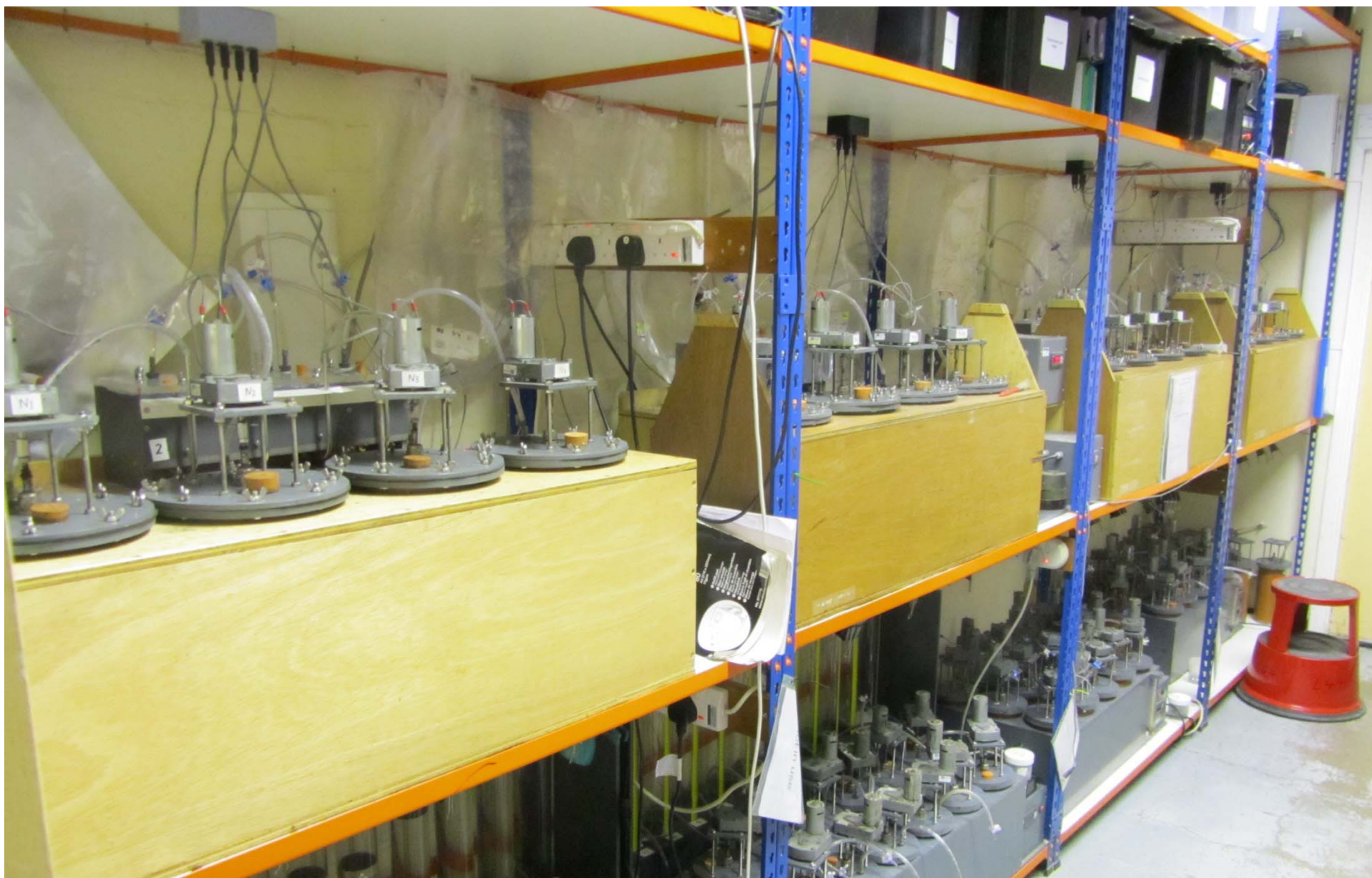


Essential trace elements for food waste digestion

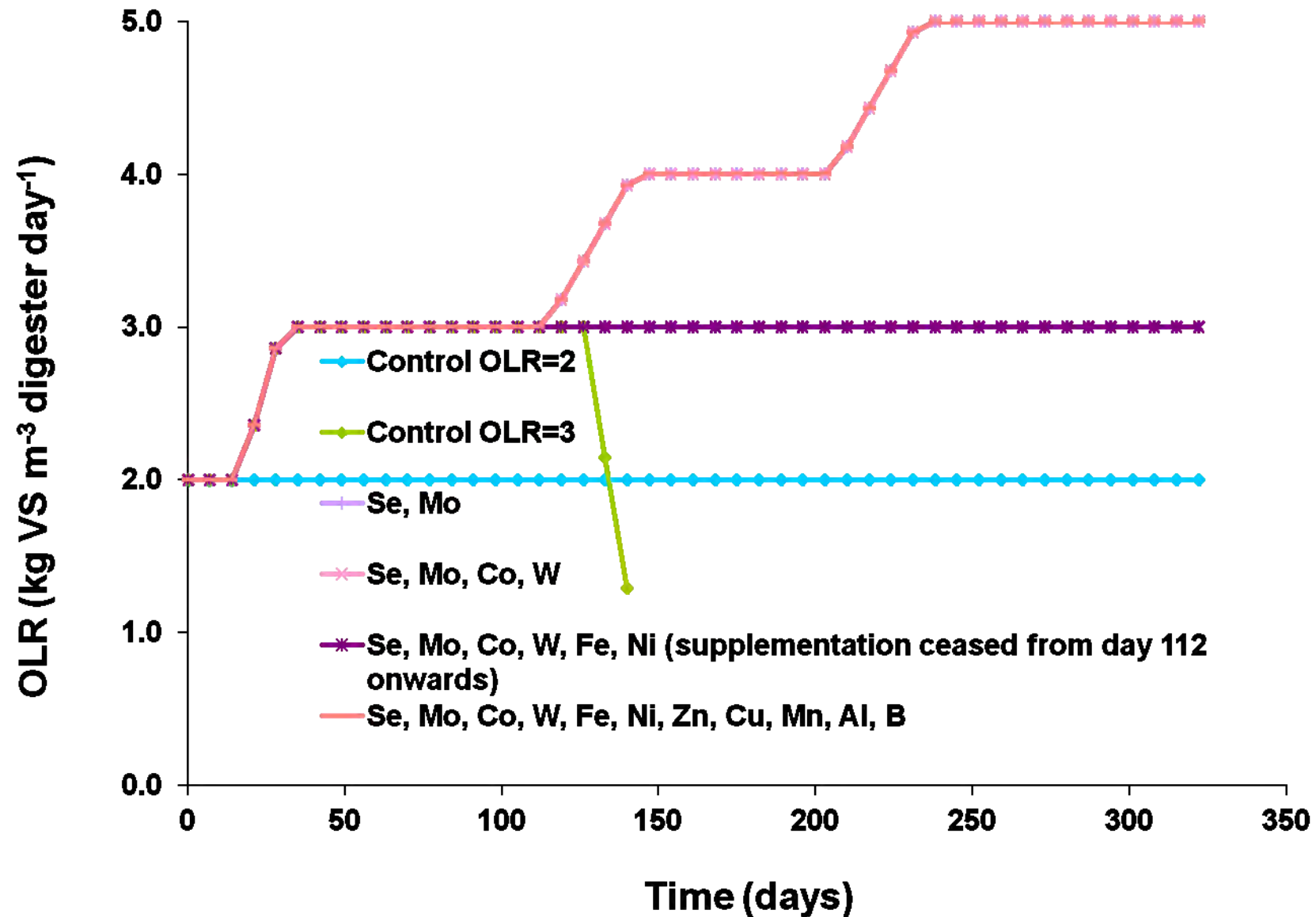
Tier	Trace element		Compound	Dosing strength (g tonne ⁻¹)
1 st	Selenium (Se)		Na_2SeO_3	0.2
	Molybdenum (Mo)		$(\text{NH}_4)_6\text{Mo}_7\text{O}_{24} \cdot 4\text{H}_2\text{O}$	0.2
2 nd	Cobalt (Co)		$\text{CoCl}_2 \cdot 6\text{H}_2\text{O}$	1.0
	Tungsten (W)		$\text{Na}_2\text{WO}_4 \cdot 2\text{H}_2\text{O}$	0.2
3 rd	Iron (Fe)		$\text{FeCl}_2 \cdot 4\text{H}_2\text{O}$	5.0
	Nickel (Ni)		$\text{NiCl}_2 \cdot 6\text{H}_2\text{O}$	1.0
4 th	Zinc (Zn)		ZnCl_2	0.2
	Copper (Cu)		$\text{CuCl}_2 \cdot 2\text{H}_2\text{O}$	0.1
	Manganese (Mn)		$\text{MnCl}_2 \cdot 4\text{H}_2\text{O}$	1.0
	Aluminium (Al)		$\text{AlCl}_3 \cdot 6\text{H}_2\text{O}$	0.1
	Boron (B)		H_3BO_3	0.1

75-litre digesters

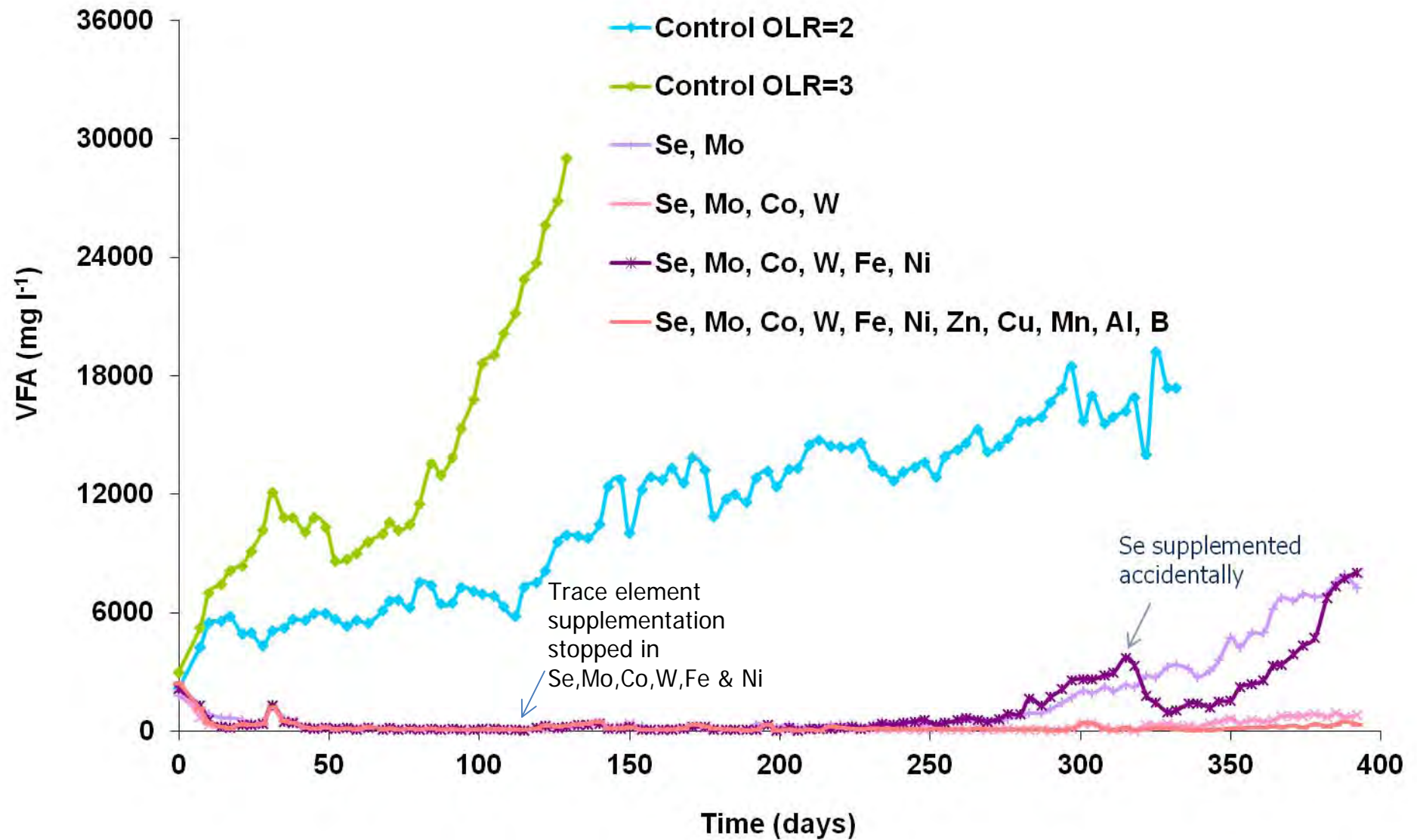




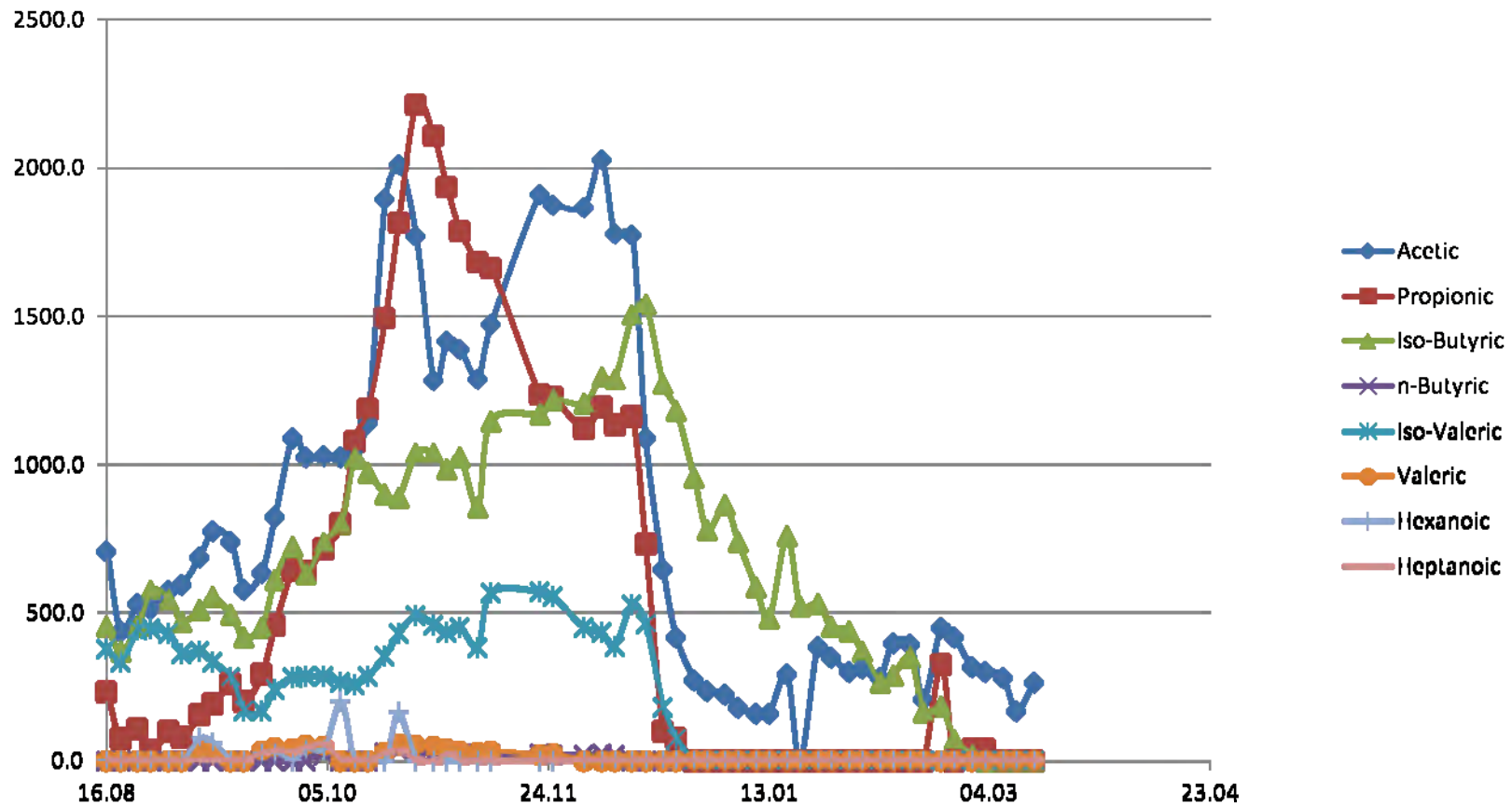
Organic loading rate (OLR)



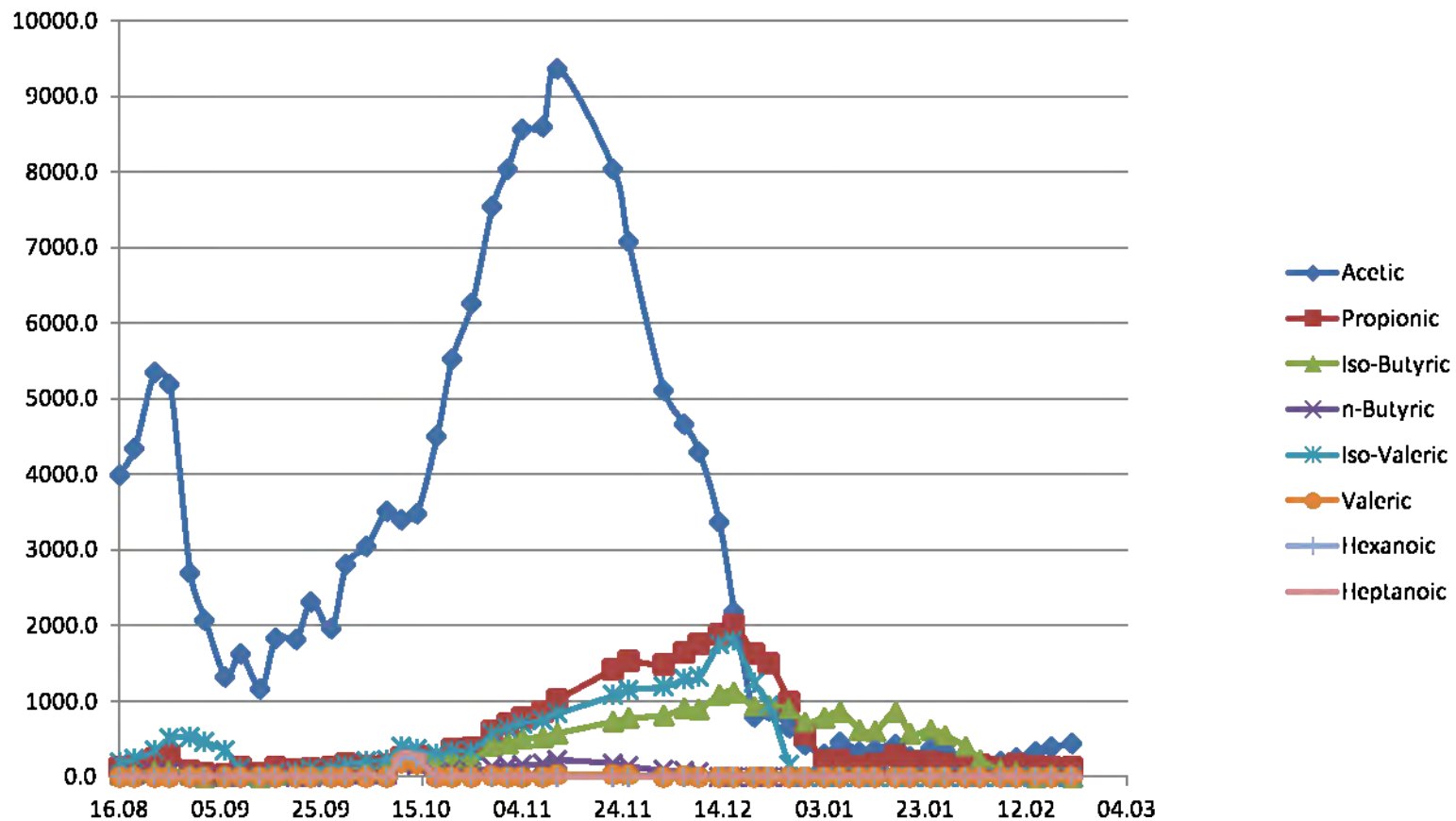
Volatile fatty acids profiles



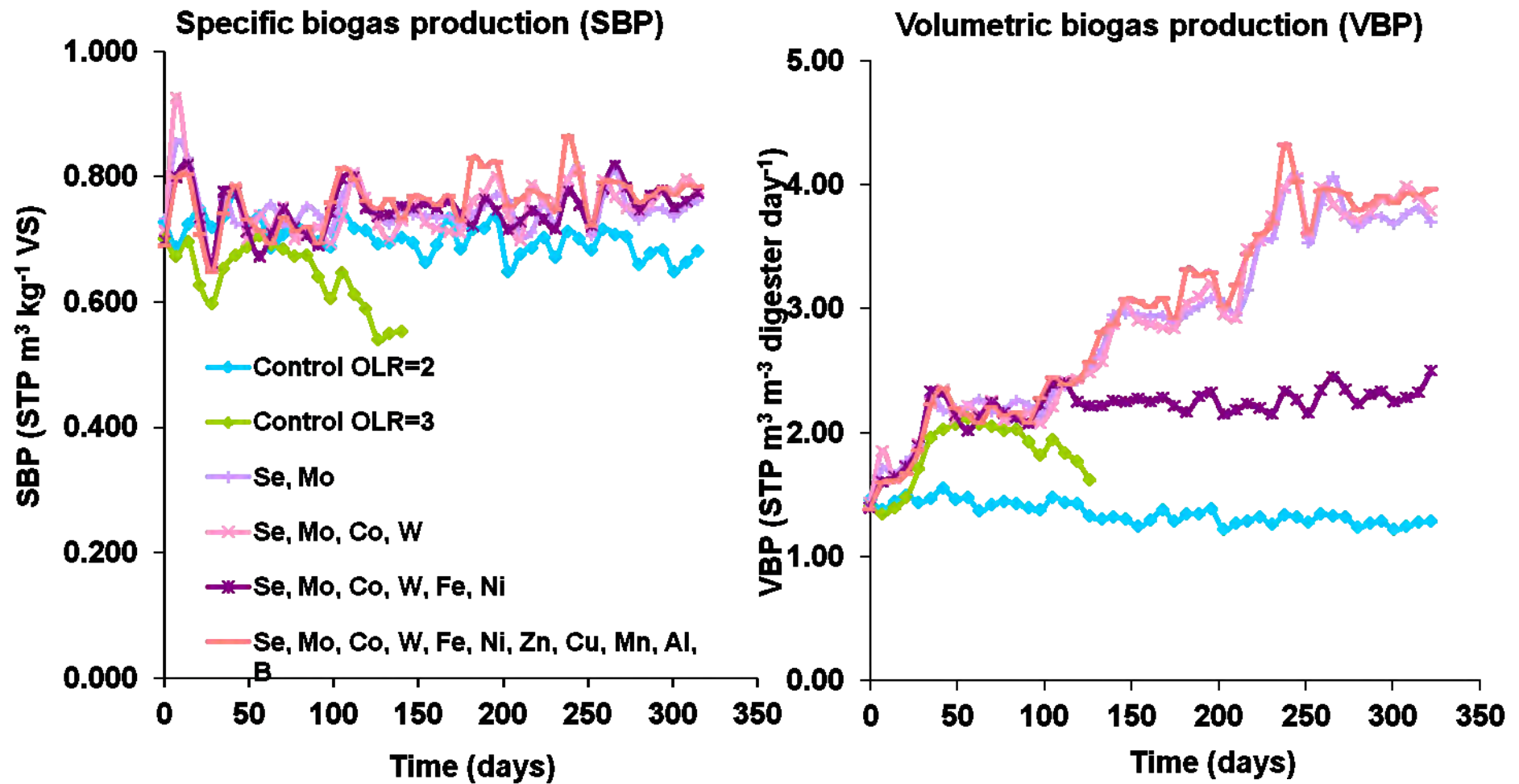
Se and Mo after Co supplementation 13/12/10



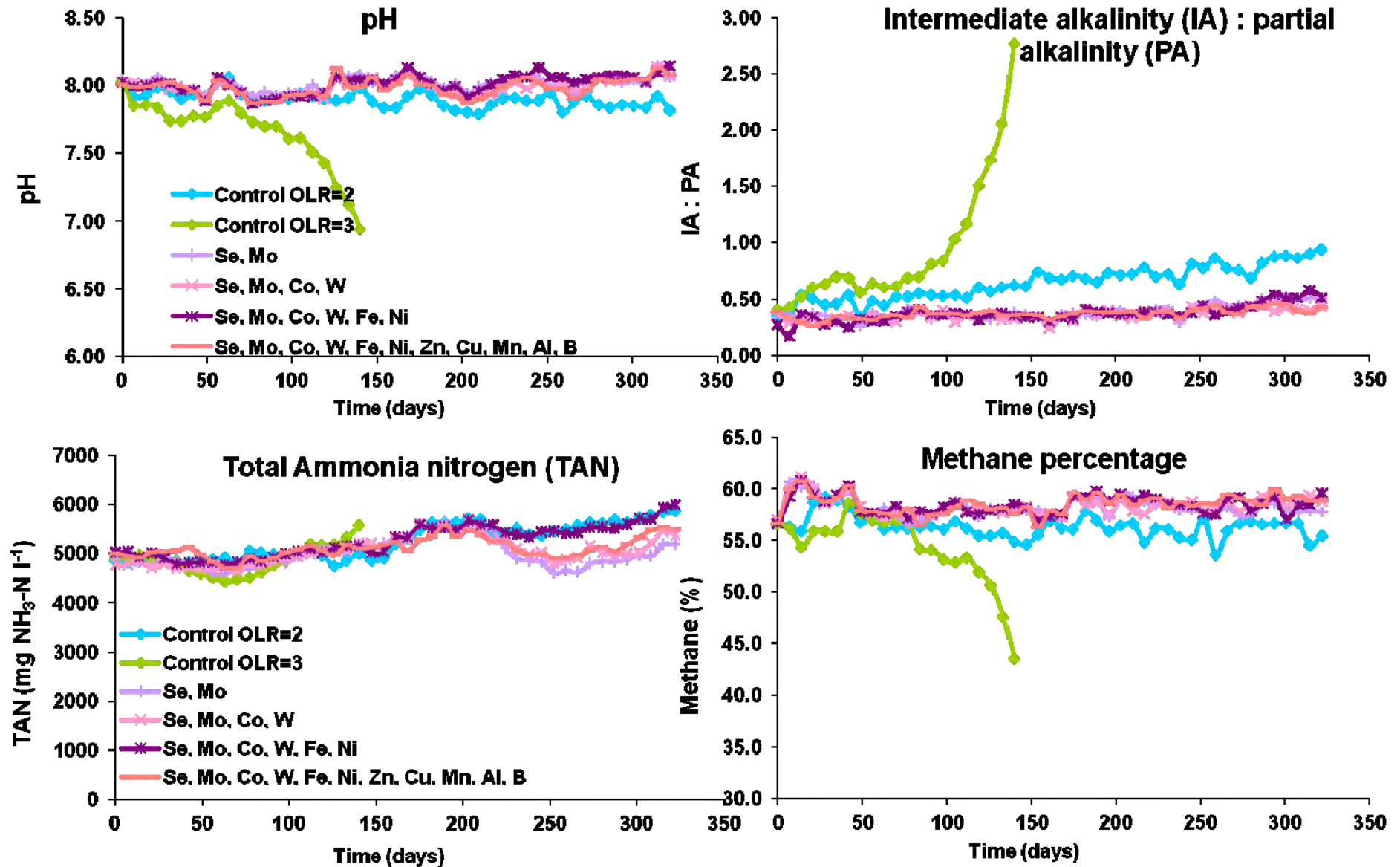
Response to Se, Co and Ni added on the 13/12/10 to digesters that had been deprived of trace elements since day 120



Digestion efficiency



Other digester parameters



TE required vs TE in the food waste

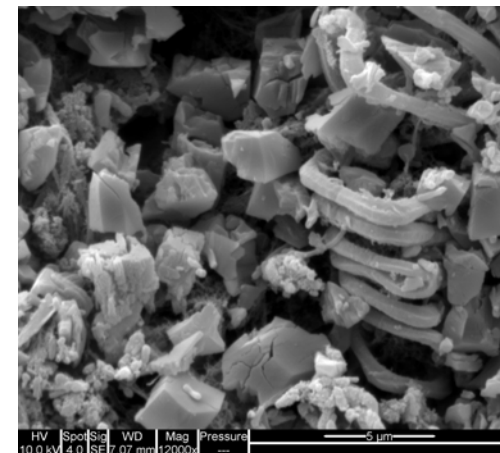
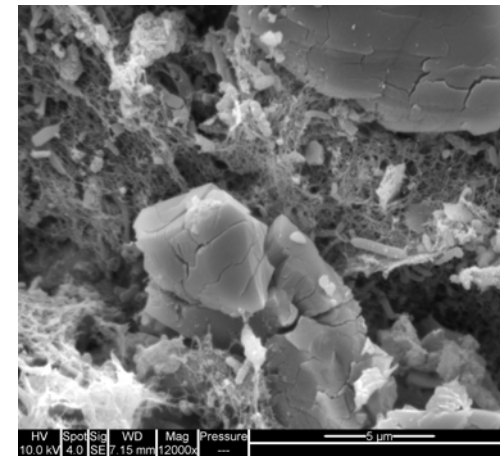
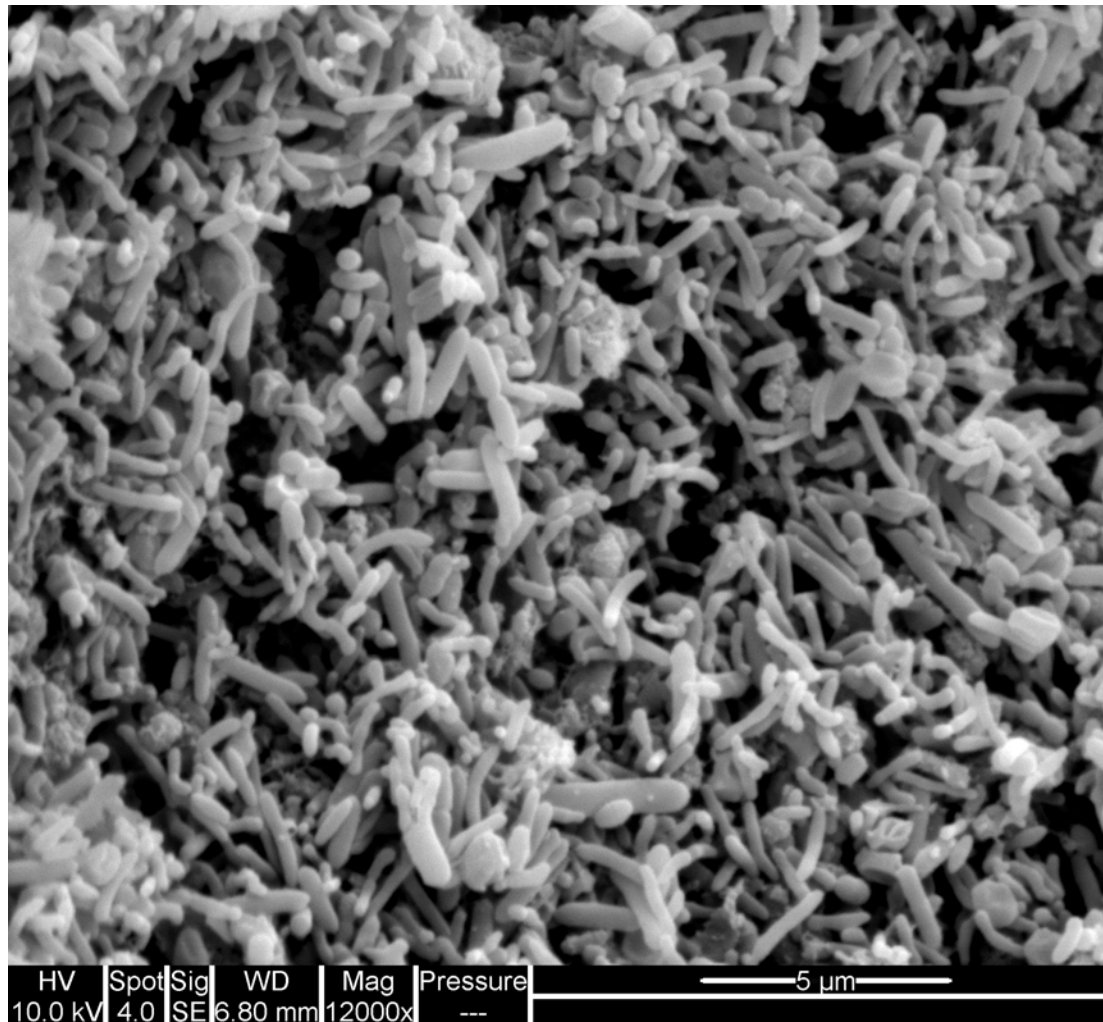
	Minimum requirement at a moderate loading rate	Hackney, London	Luton, South Bedfordshire	Ludlow, Shropshire
Co	0.22	0.090 ± 0.049	0.017 ± 0.002	< 0.060
Se	0.16	0.10 ± 0.08	0.28 ± 0.14	< 0.07
TKN	-	8100	7400	8100

Unit: mg kg^{-1}
fresh matter

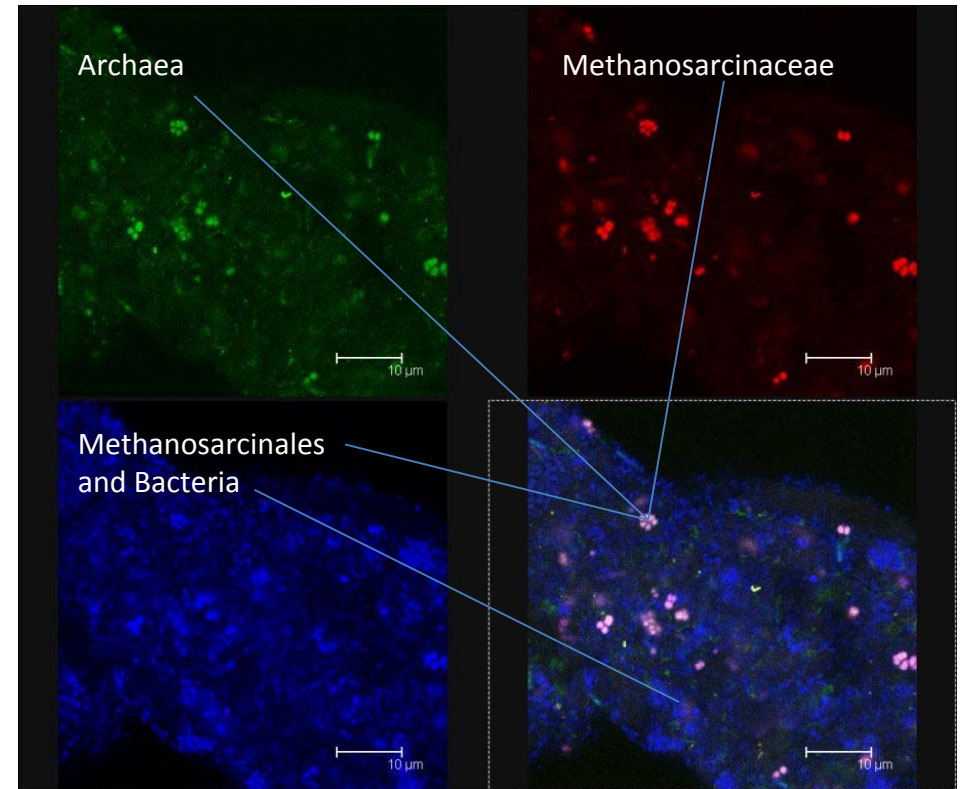
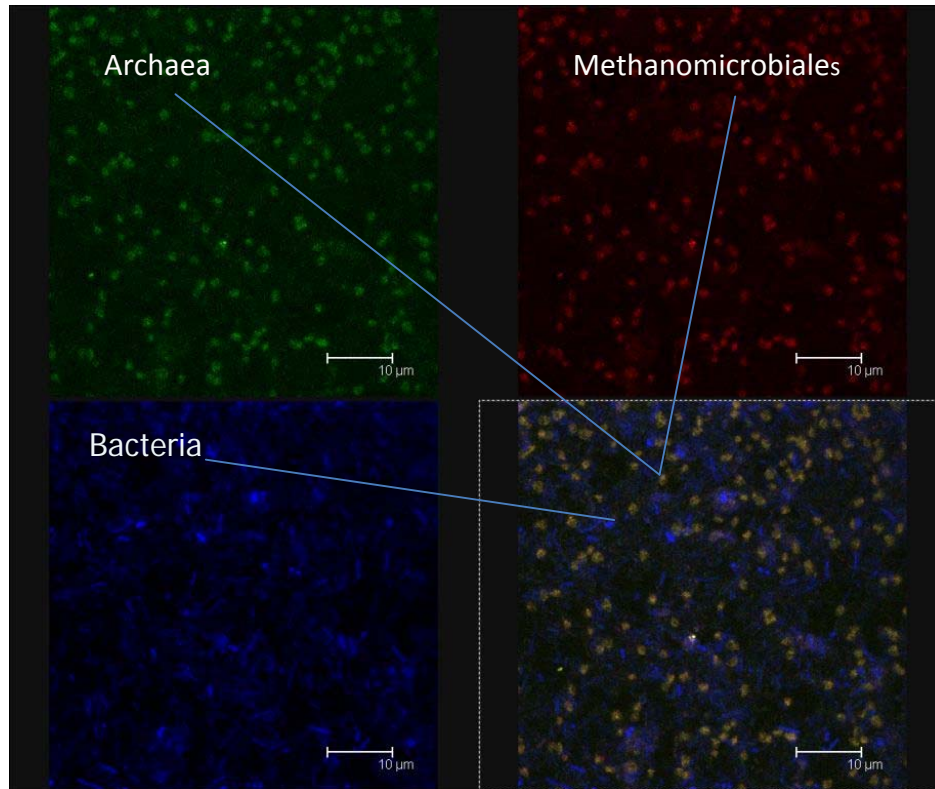
Classification of Methanogens

Methanogen	Carbon source
Order I. Methanobacteriales	CO ₂ / H ₂ and formate
Order II. Methanococcales	CO ₂ / H ₂ and formate
Order III. Methanomicrobiales	CO ₂ / H ₂ and formate
Order IV. Methanosarcinales	
Family I. Methanosaetaceae	Acetate
Family II. Methanosarcinaceae	Acetate Methylated one-carbon compounds CO ₂ / H ₂ and formate

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	<i>Bacteria</i>	GCTGCCTCCCGTAGGAGT	Cy5	blue	20~50
ARC915	<i>Archaea</i>	GTGCTCCCCGCCAATTCCT	6-Fam	green	20~50
MG1200	<i>Methanomicrobiales</i>	CGGATAATTCGGGGCATGCTG	Cy3	red	20
MS1414	<i>Methanosarcinaceae</i>	CTCACCCATACCTCACTCGGG	Cy3	red	50
MSMX860	<i>Methanosarcinales</i>	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 $5 \text{ kg VS m}^{-3} \text{ d}^{-1}$ with a volumetric biogas production of $3.8 \text{ STP m}^3 \text{ m}^{-3} \text{ d}^{-1}$ and specific biogas production of $0.76 \text{ STP m}^3 \text{ kg}^{-1} \text{ VS}$
- 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



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Dr Yue Zhang, Biogen-Greenfinch

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



VALORGAS