Multi-Stage Anaerobic Co-Digestion of Food Waste and Waste Activated Sludge

Le Zhang, Kai-Chee Loh, Jingxin Zhang, Liwei Mao, Yen Wah Tong, Chi-Hwa Wang, Yanjun Dai

Email: zhangle@u.nus.edu

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Outline

1. Introduction
2. Research problem & analysis
3. Experimental design
4. Results and discussion
5. Conclusion and future work

1. Introduction

Food waste issue
Sludge issue

Waste management and recycling statistics for 2018

Waste Type	Waste Disposed of (tonnes)	Waste Recycled (tonnes)	Waste Generated (tonnes)	Recycling Rate (%)
Food	636,900	126,200	763,100	17%
Ash and sludge	215,200	24,600	239,800	10%

- **Source:** *National Environment Agency (NEA) in Singapore*
- **Food waste and Waste Activated Sludge: Biomass resources !**
- Recycling rate is low
- Potential environmental pollution

Strategy: Anaerobic digestion technology, waste to energy

2. Research problem & analysis

Anaerobic digestion (AD) technology

Food waste
Waste Activated Sludge

↓

Organic matters

↓ + Inoculum

Hydrolysis and Acidogenesis (1)

↓ Volatile fatty acids

Acetogenesis (2)

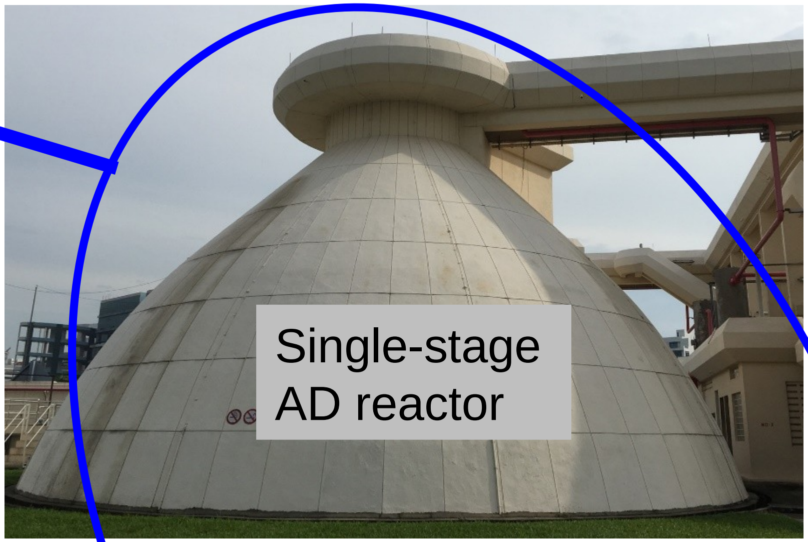
↓ Acetate and Hydrogen

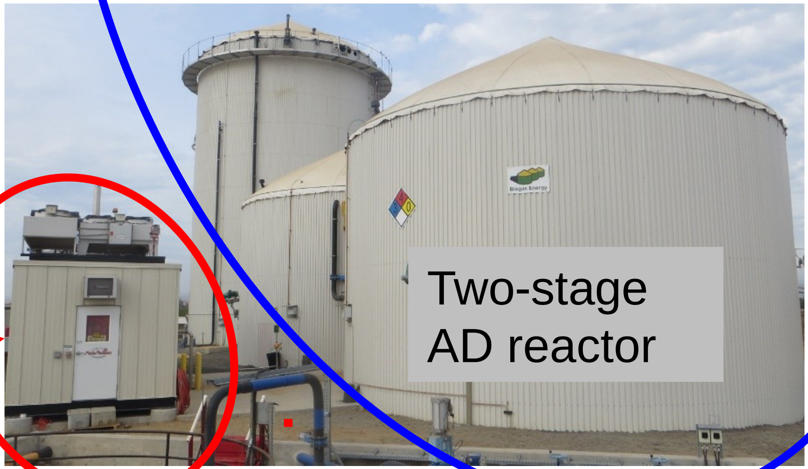
Methanogenesis (3)

↓

Biogas (Methane)

Fuel: natural gas
Chemical feedstock





Electricity generator

2. Research problem & analysis

Anaerobic digestion (AD) technology

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Waste Activated Sludge

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Methanogenesis (3)

↓

Biogas (Methane)

Fuel: natural gas
Chemical feedstock

Main problem:

Given a digester chamber (one or two stage)

↓

Only one or two pH allowed

✕

Different optimal working pH

Three chambers simultaneously?

↓

Three different optimal working pH

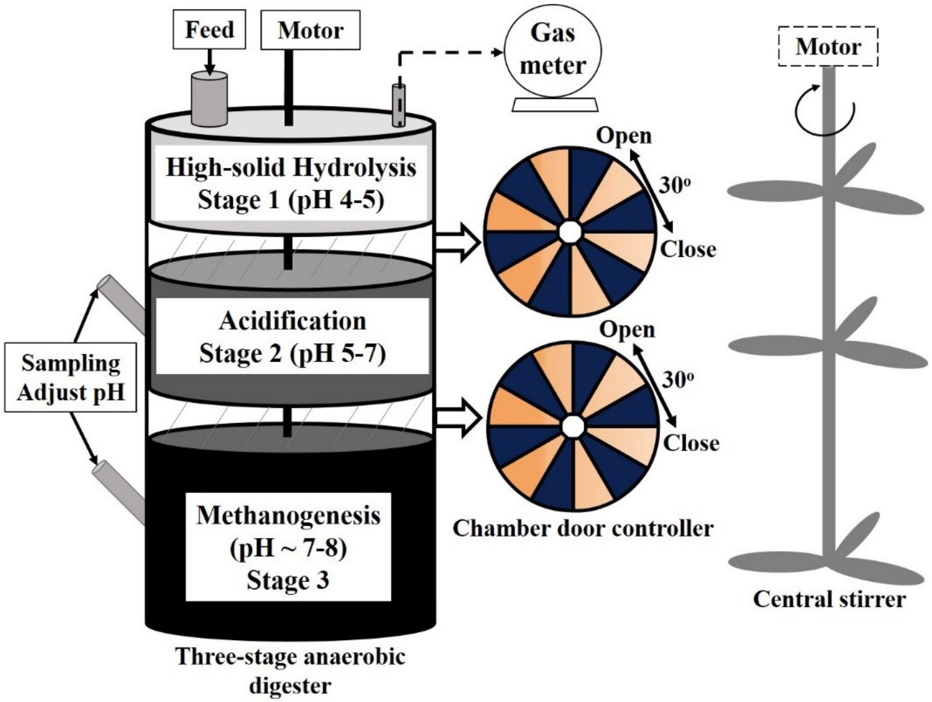
↓

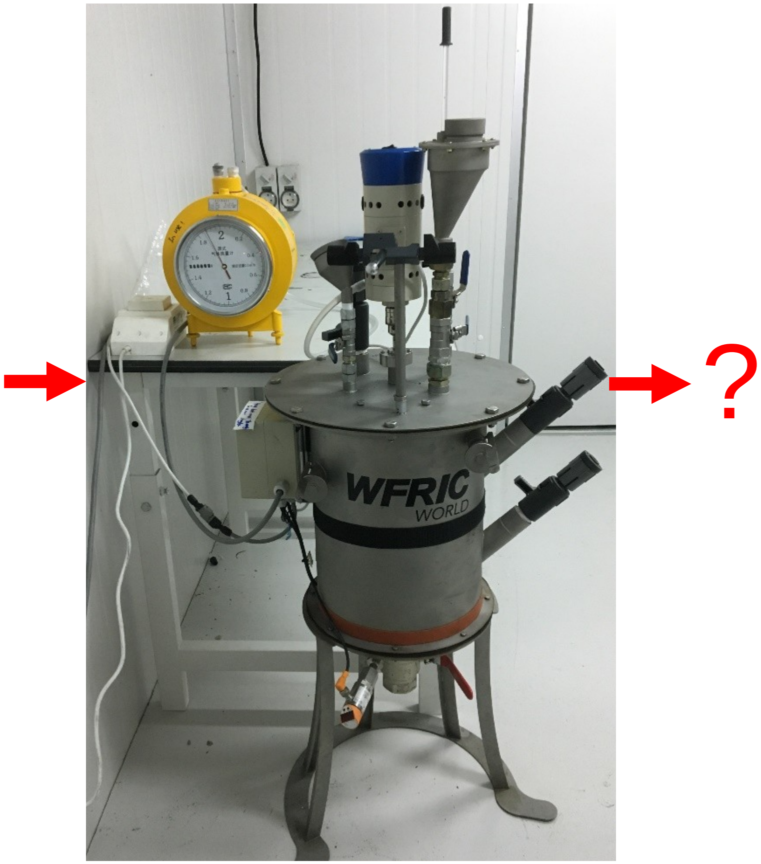
Optimized AD process

2. Research problem & analysis

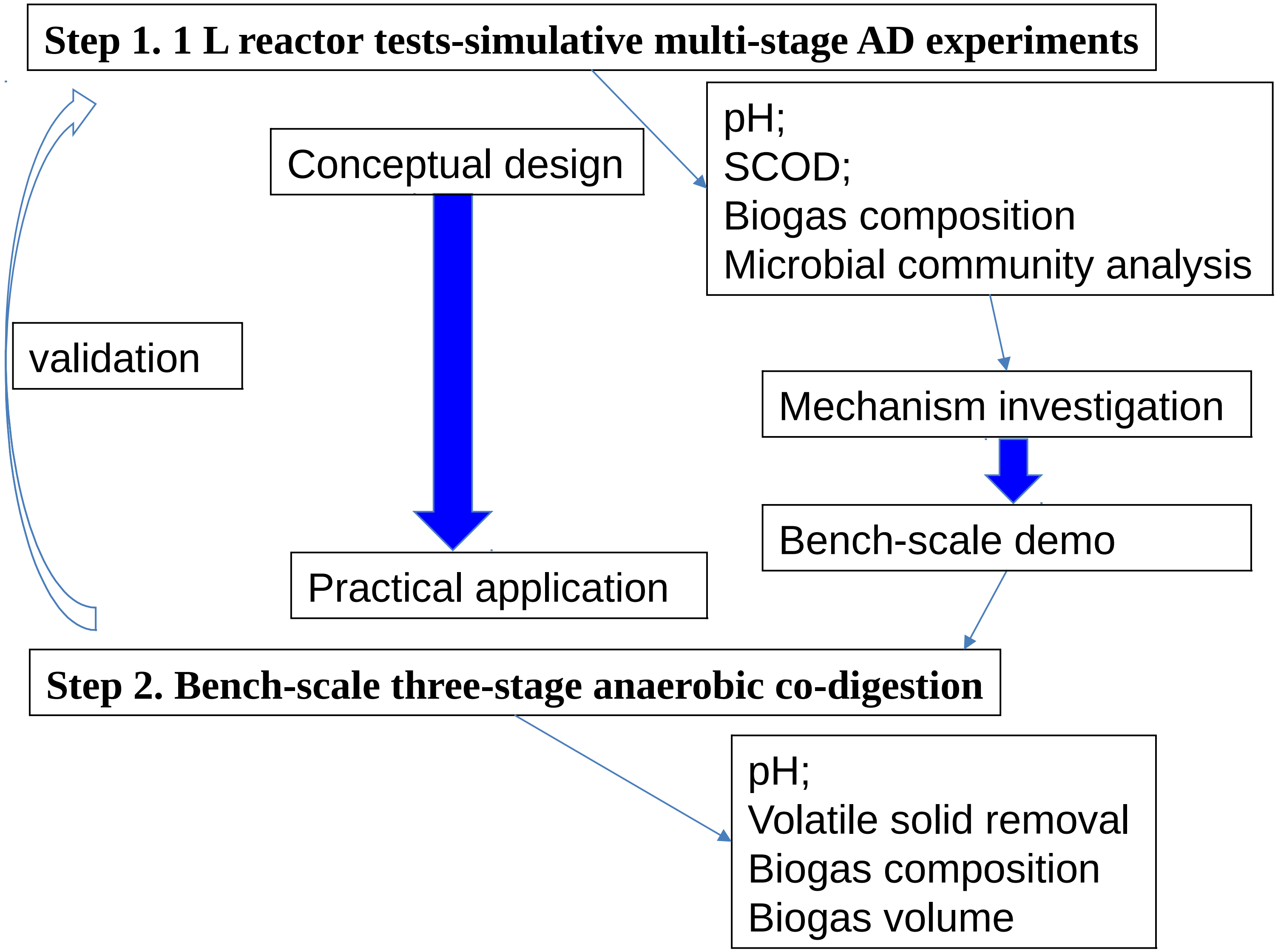
- **Proposed approach:** **three-stage anaerobic co-digestion of food waste and waste activated sludge**

Hypothesis:





3. Experimental design



4. Results and discussion

4.1. Detailed characteristics of substrates and inoculum

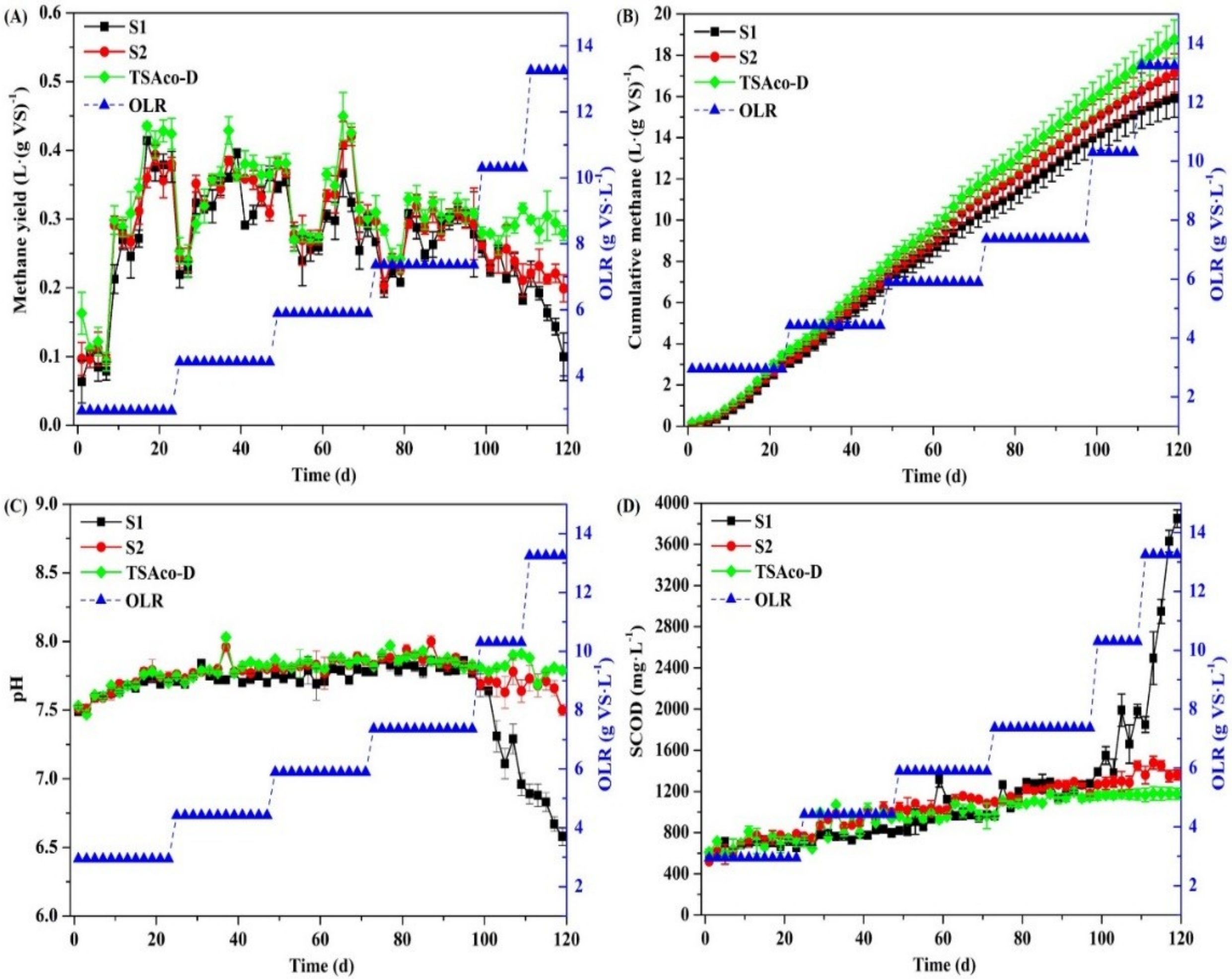
Table 1. Detailed characteristics of substrates and seed sludge.

Characteristics	Unit	Seed sludge	FW	WAS	Co-substrate
TS	wt%	1.71 ± 0.01	28.29 ± 0.51	14.93 ± 0.20	21.19 ± 0.28
VS	wt%	1.22 ± 0.01	27.15 ± 0.49	11.29 ± 0.11	18.84 ± 0.20
VS/TS ratio	-	0.71	0.96	0.76	0.89
pH	-	7.61 ± 0.1	5.21 ± 0.1	8.60 ± 0.2	6.51 ± 0.1
Carbon	%	33.56 ± 0.04	49.70 ± 0.41	32.25 ± 0.02	43.12 ± 0.42
Hydrogen	%	4.78 ± 0.03	8.40 ± 0.05	5.27 ± 0.04	6.89 ± 0.07
Nitrogen	%	5.41 ± 0.05	2.20 ± 0.03	5.33 ± 0.07	2.86 ± 0.05
C/N ratio	-	6.20	22.59	6.05	15.08

VS ratio = 1:2.5 (WAS/FW)

4. Results and discussion

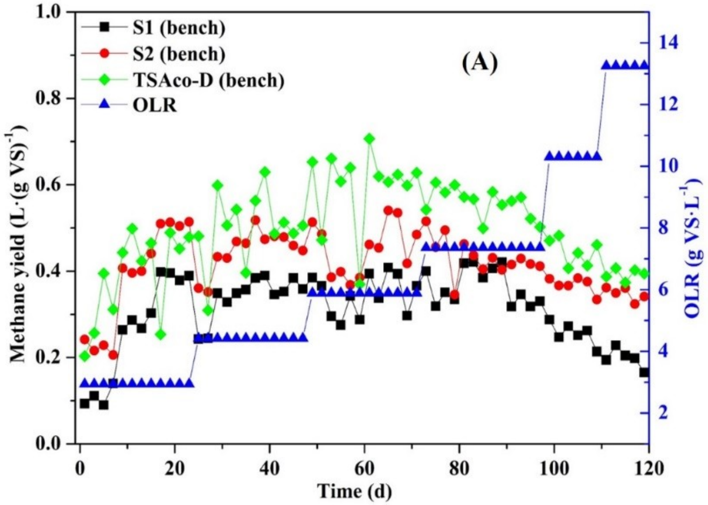
4.2. Overall performance in simulative multi-stage AD experiments



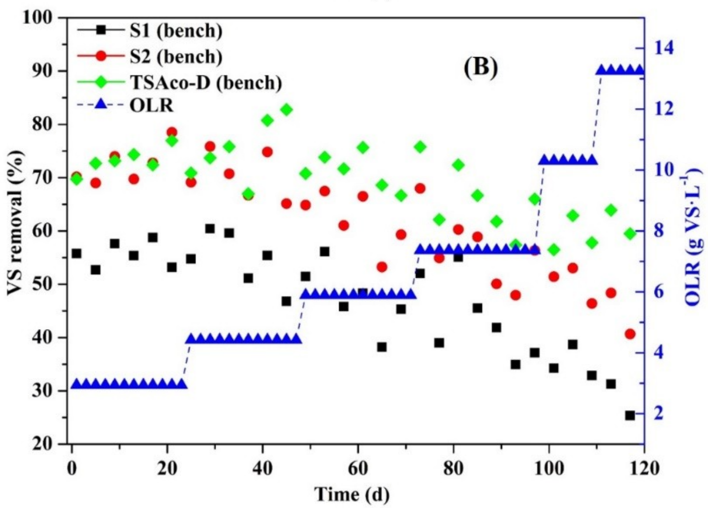
- 2.94 to 13.25 gVS/L
- TSAco-D : highest average daily specific methane yield, 0.395 L/gVS, 19.3-49.1% higher than single and two stage reactors
- pH and SCOD: explained changing tendency of methane yields

4. Results and discussion

4.3. Performance of bench-scale three-stage anaerobic co-digestion



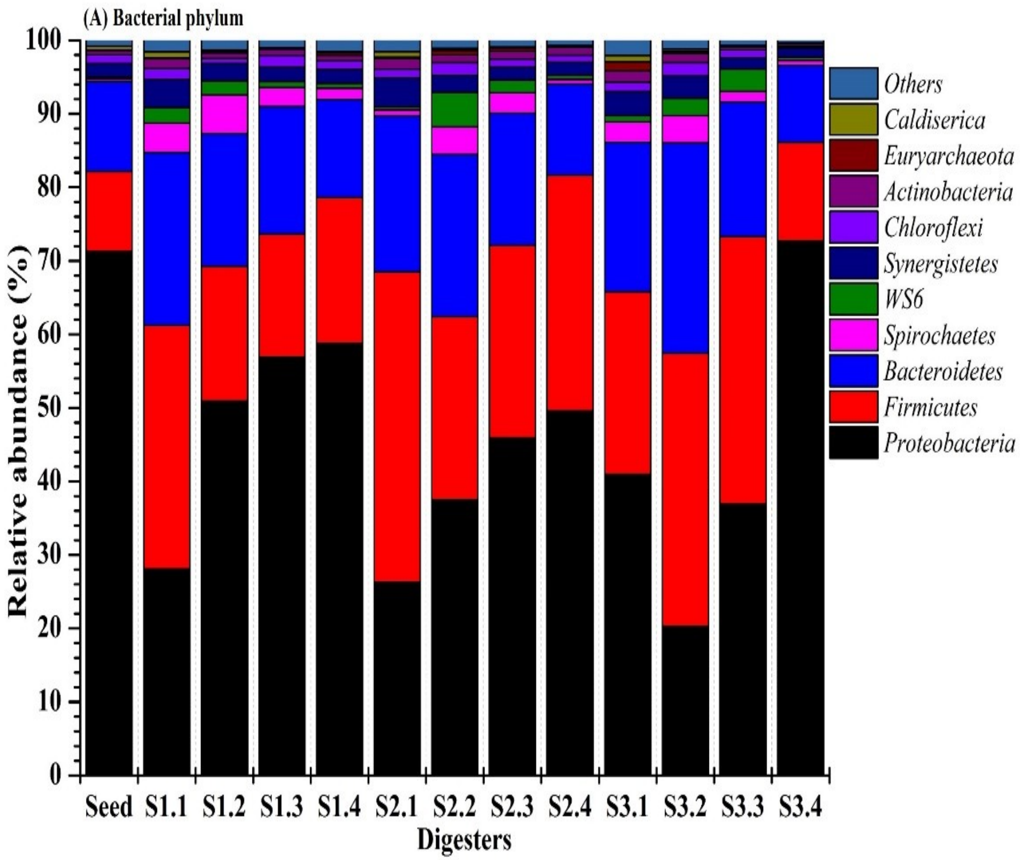
- Methane yields: 0.496 L/(gVS)
- Maximum available OLR was between 6 and 7 g VS·L^{-1}
- A better bearing capacity for a high OLR than one- and two-stage digesters



- Average VS reduction of TSAco-D (bench) reached 69%
- 12-47% higher than that of one- and two-stage digesters
- A higher VS removal efficiency in the three-stage AD process validated

4. Results and discussion

4.4. Analysis of microbial communities - Bacterial communities

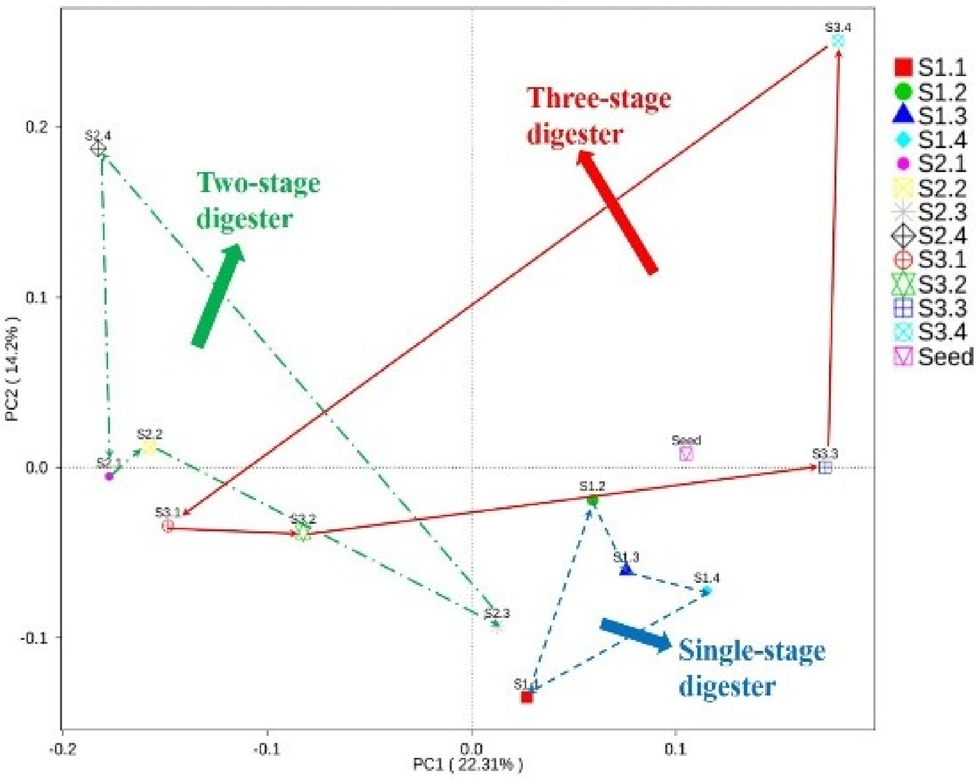


- Dominant species in three-stage digester according to the relative abundance were *Proteobacteria* (42.7 ± 19.0%), *Firmicutes* (28.0 ± 9.7%), *Bacteroidetes* (19.4 ± 6.5%), *Spirochaetes* (2.2 ± 1.2%), *WS6* (1.7 ± 1.1%), *Synergistetes* (2.3 ± 0.9%), *Chloroflexi* (1.1 ± 0.6%), *Actinobacteria* (0.9 ± 0.5%), *Euryarchaeota* (0.4 ± 0.5%), and *Caldiserica* (0.3 ± 0.3%).

4. Results and discussion

4.4. Analysis of microbial communities - Bacterial communities

(B) PCoA of bacterial community at phylum level

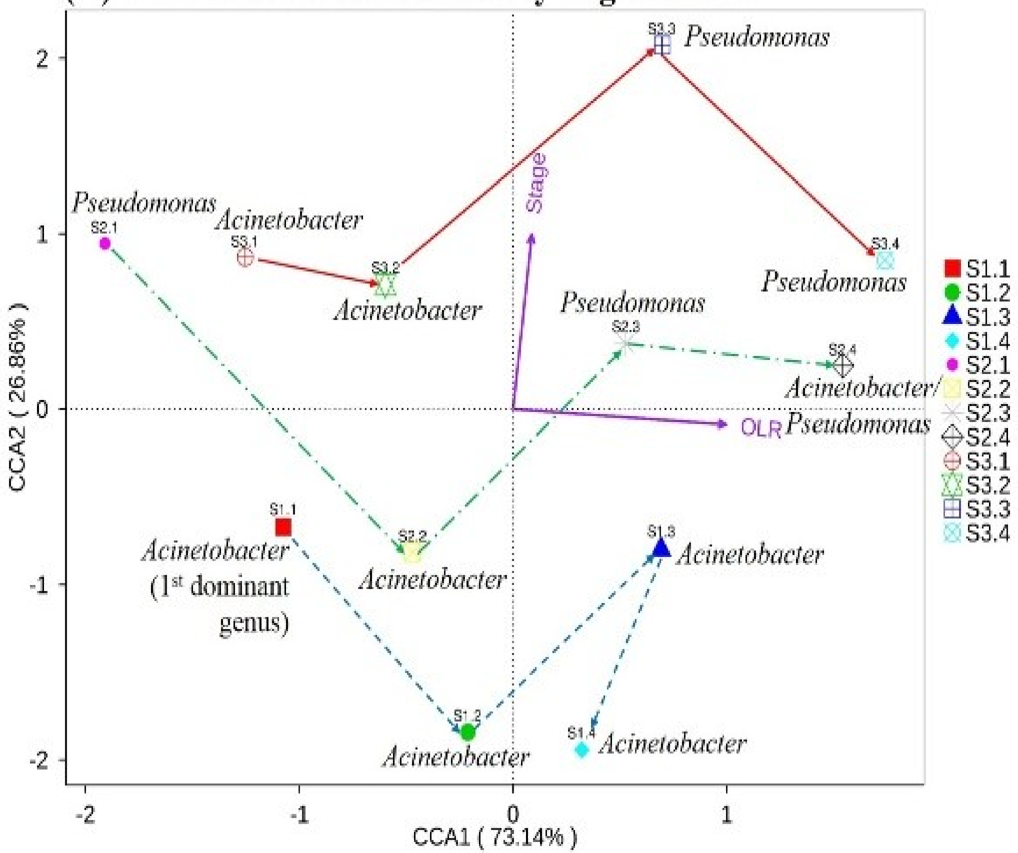


- PCoA analysis revealed that the dominant microbes species composition in response to increase of digester stage number were distinctly different among one-, two-, and three-stage digesters.

4. Results and discussion

4.4. Analysis of microbial communities - Bacterial communities

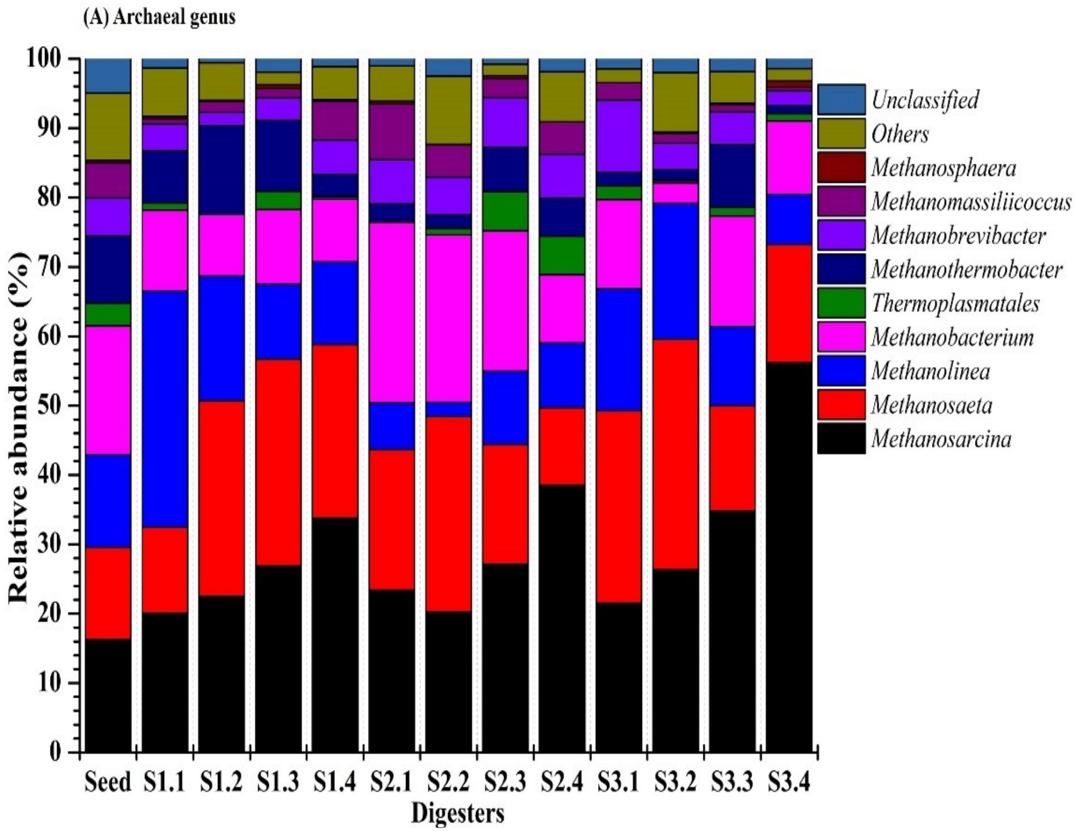
(C) CCA of bacterial community at genus level



- CCA: the most predominant species of bacterial communities dynamically shifted along with the increasing stage number and OLR;
- Above results indicated that community structures varied in response to these two process variables.

4. Results and discussion

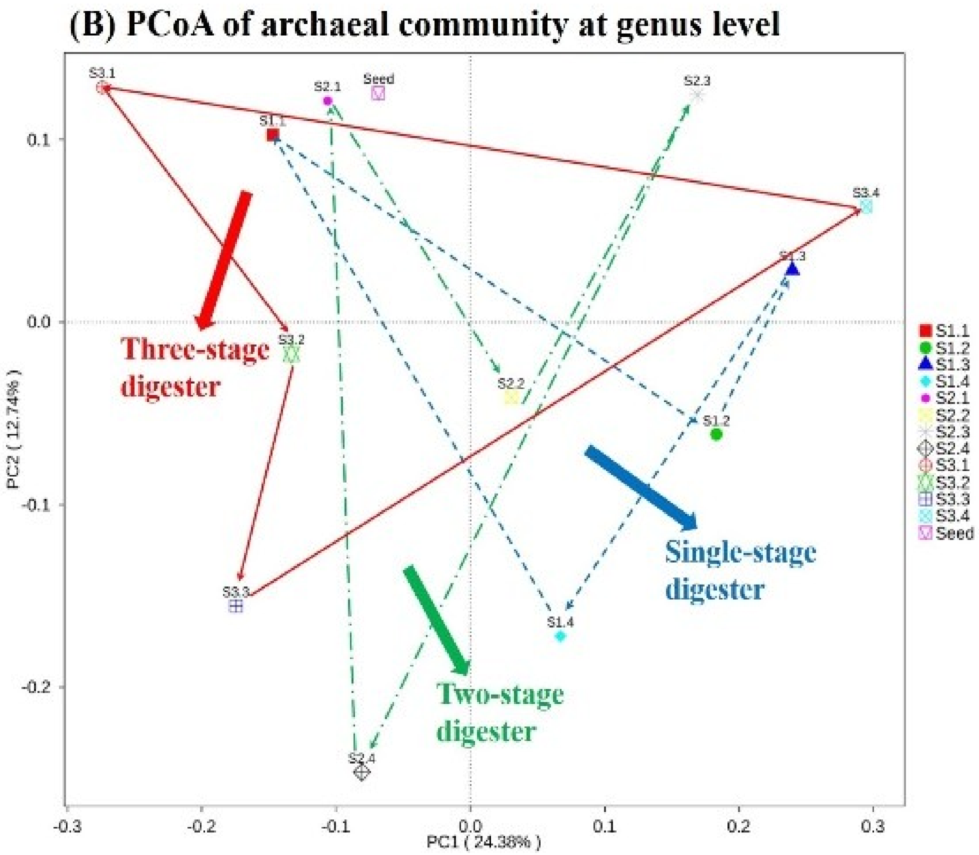
4.5. Analysis of microbial communities - Archaeal communities



- Methanogen genera : *Methanosarcina* (29.3 ± 9.9%), *Methanosaeta* (22.1 ± 7.1%), *Methanobacterium* (13.6 ± 6.5%), *Methanolinea* (13.3 ± 7.9%), *Methanothermobacter* (5.3 ± 3.7%), *Methanobrevibacter* (5.0 ± 2.3%), *Methanomassiliicoccus* (2.9 ± 2.2), and *Thermoplasmatales* (1.7 ± 1.9%)

4. Results and discussion

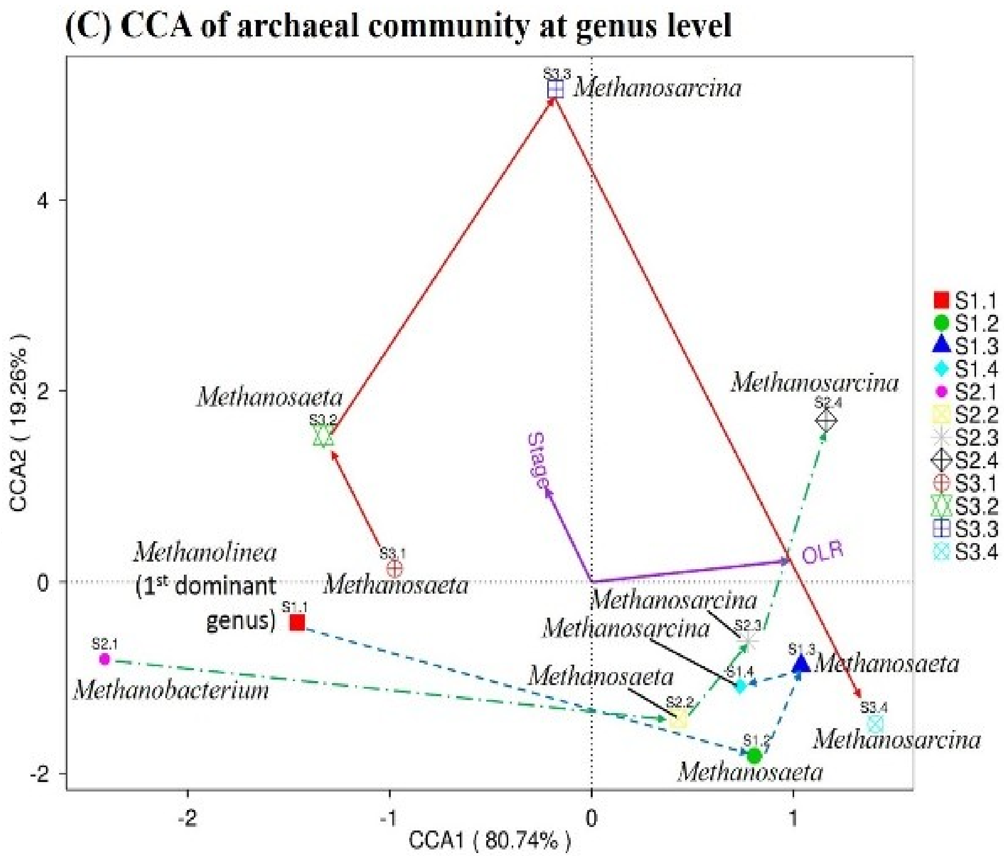
4.5. Analysis of microbial communities - Archaeal communities



- Both digester stage and OLR were crucial environmental variables shaping the taxonomic patterns of the methanogens.

4. Results and discussion

4.5. Analysis of microbial communities - Archaeal communities



- Included angle of the vector of the [stage] and the vector of [OLR] was larger than 90°, indicating that the effects of stage number had the negative correlation with OLR.

- Dominant methanogenic pathway had a tendency of shifting from hydrogenotrophic pattern to acetoclastic pattern

5. Conclusion & Future work

Conclusion

1. FW and waste activated sludge were co-digested in a three-stage anaerobic digester
2. Functional segregation favored selective enrichment of bacteria and methanogens
3. *Methanosarcina* in a three-stage digester was 1.5-1.7 times higher than the controls
4. Average methane yield and VS removal increased by 13-52% and 12-47%, respectively
5. Feasibility of a bench-scale three-stage anaerobic digester scenario was validated

Future work

1.Still need a longer running period in a continuous and recycled mode

2.For pH control in different stages, automatic regulating equipment may be introduced into the system

3.For potential industrial application of this new reactor, the economic feasibility analysis involving energy balance should be conducted

Acknowledgements

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E2S2 Website: http://e2s2-create.org/index.html
Address: 1 CREATE Way, CREATE Tower, #15-02 Singapore 138602

Thank you!