Anaerobic Digestion of Non-diluted Food Waste
: Strategies for stable operation under high organic loading

Dong-Hoon Kim, Mi-Sun Kim

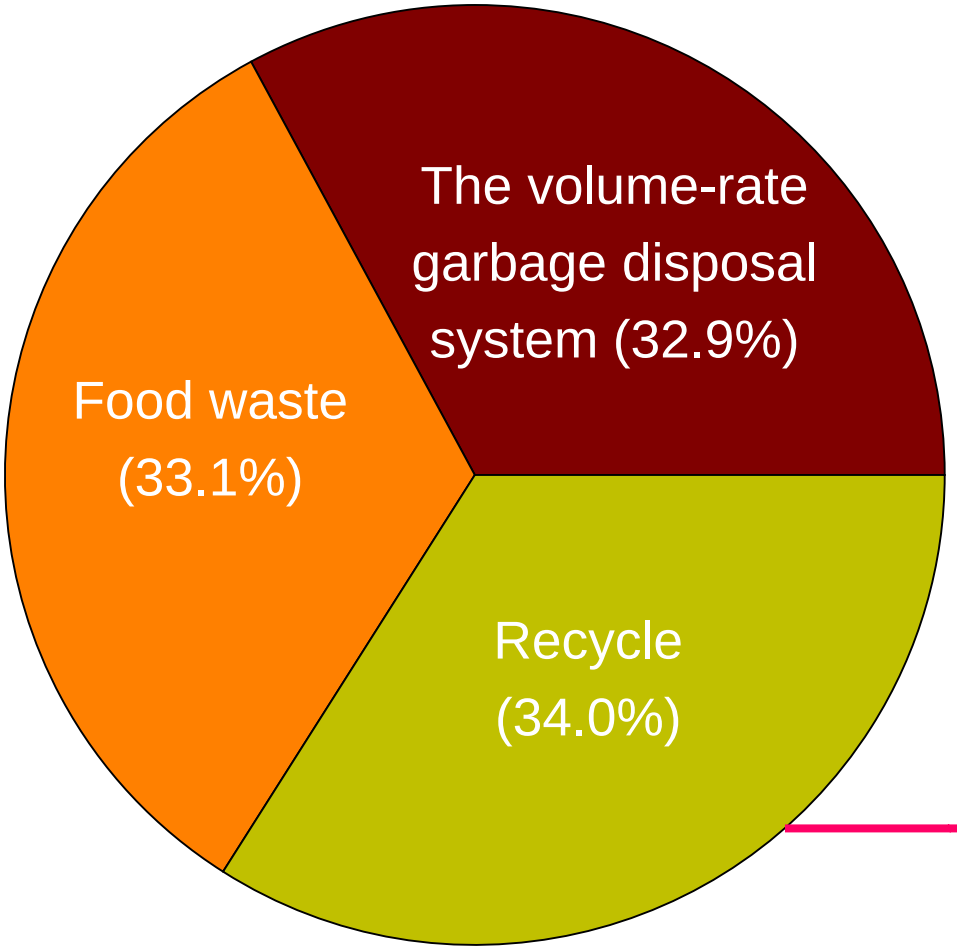
Clean Fuel Department, Korea Institute of Energy Research

14 Nov. 2013

Renewable Energy Biogas Technologies Workshop

Municipal wastes production in Korea

940.4 g waste/d/person



<standardize envelope>

paper, plastic, food waste

Items	Percentage (%)
Paper	44.5
Plastic	23.8
Glass	17.5
Waste can	6.3
Iron	2.5
Etc.	5.4

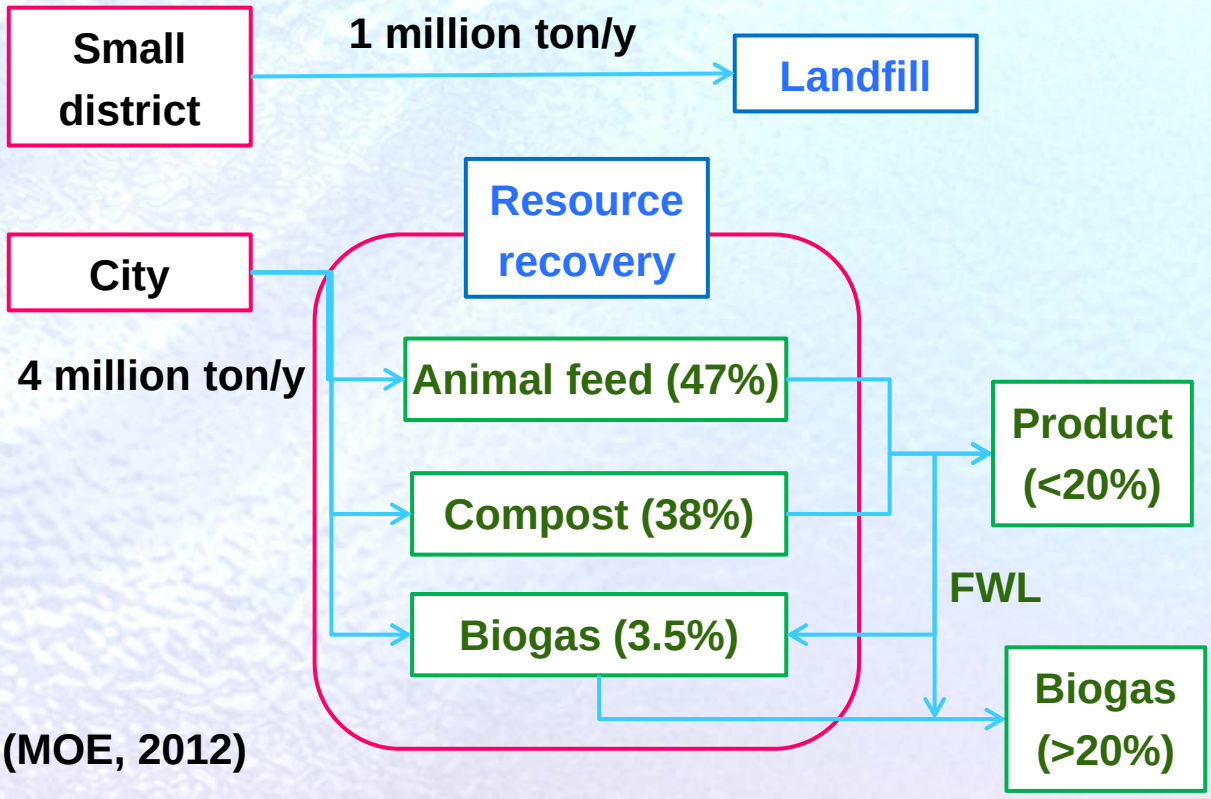
<MOE, 2012>

Food waste production in Korea

Items	Percentage (%)
Vegetable	31.1
Fruit	19.9
Grain crop	20.1
Meat & fish	14.1
Leachate	5.4
Etc.	9.4

Items	Unit	Value
pH		3.9-4.1
Water content	%	80
Ash	%	4.5

Items	Unit	Value
C	% TS	45.89
H	% TS	6.36
O	% TS	35.30
N	% TS	2.55
S	% TS	0.06
C/N		18



(MOE, 2012)

Biogas boom in Korea

Waste to Energy Policy

- Till 2020
  - Constructionn of 28 biogas plant (100 ton/d>)
  - Biogas injection to gas grid
  - Market size will grow 2 billion $

Prohibition of ocean dumping

- London convention
- Sludge and livestock waste (2012)
- Food waste leachate (2013)
- Wastewater sludge (2016)

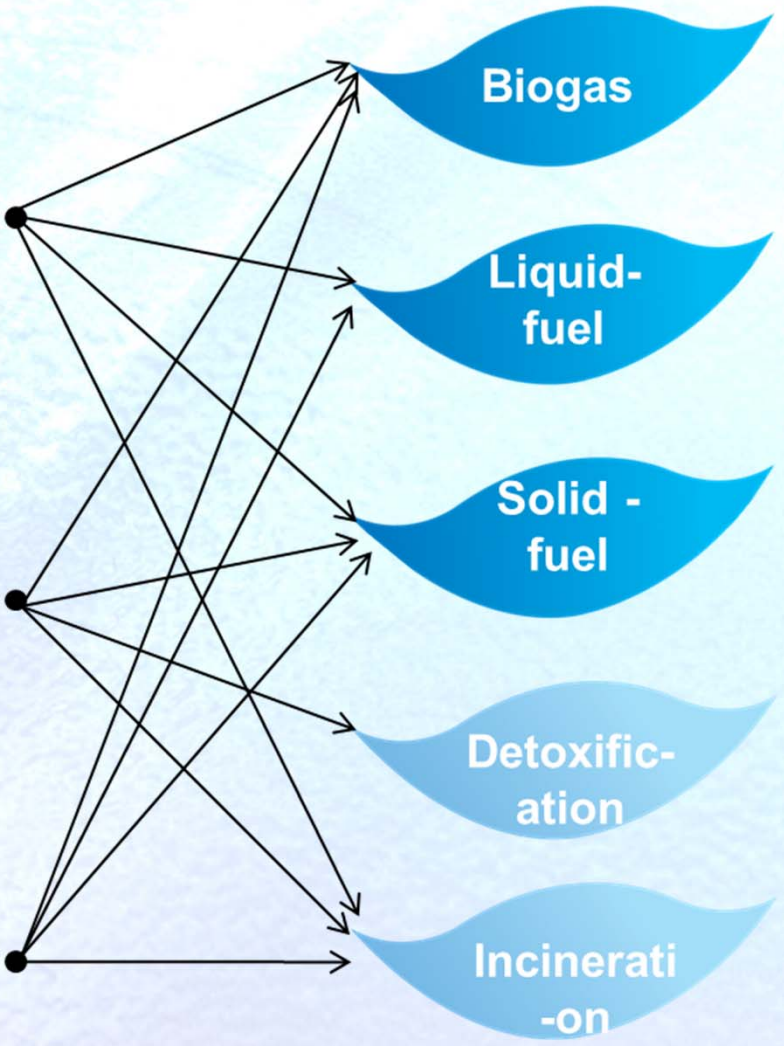
RPS, RFS

- Reneable portfolio standards

⇒ 2% in 2012 , 10% in 2022

- Renewable fuel standard

⇒ Biogas in 2016



Research Objectives

Anaerobic digestion of non-diluted food waste

- **Minimal hear requirement and less sludge production**
- **Little information in Korea**
- **How high OLR can be treated ? Strategy to increase OLR ?**
- **Salt toxicity ?**

Strategies for stable operation	Salt toxicity
• Mesophilic vs. Thermophilic • Step-feeding • Trace metal addition • SBR (Settling)	• 0-18 g Na/L • Analysis of acids and biogas

Materials and Methods

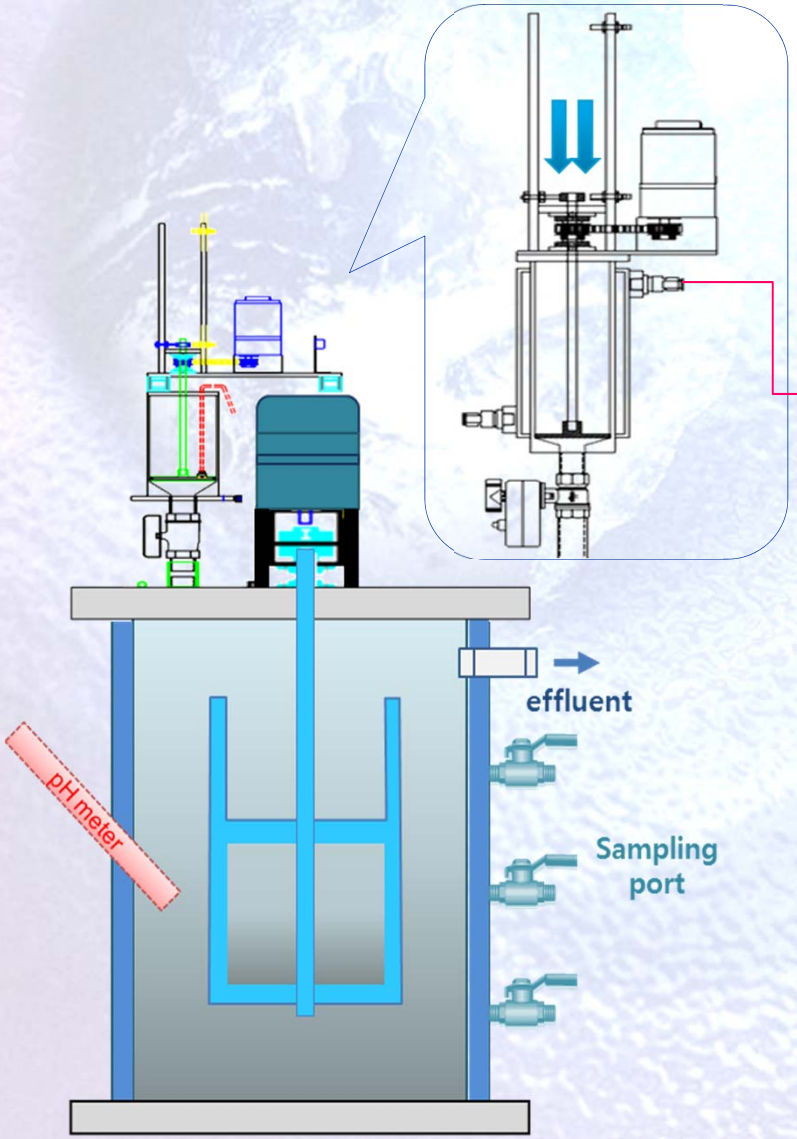
Characteristics of food waste & seeding source

Item	Unit	Value		
		Food waste	ADS[a]	Granular sludge
TS (Total solids)	g TS/L	190	31.4	157.3
VS (Volatile solids)	g VS/L	170	17.0	102.6
Total COD	g COD/L	220	24.1	ND[b]
Carbohydrate	g/L	115	1.4	ND[b]
TN (Total Nitrogen)	g N/L	2.5	ND[b]	1.7
Alkalinity	g $CaCO_3$/L	-	2.8	6.7
pH	-	4.0	7.4	7.5

[a]ADS = anaerobic digester sludge
[b]ND = not determined
[c]Supernatant = after grinding and centrifugation

Materials and Methods

Reactor scheme



Reactor

- Volume: effective volume = 10 L (total 12L)
- Stirrer shape (‘ㅂ’ shape)
- Temperature control: water jacket
- pH monitoring
- Feeding control: timer installed syringe
- Circulating cold water to prevent FW decay

Operation strategy

- HRT(day): 200 (150) → 100 → 80 → 60 → 50 → 40
- OLR (kg TS/m^3/d): 1 → 2 → 2.5 → 3.3 → 4.0 → 5.0
- Mesophilic vs. Thermophilic / Step-feeding / Trace metal addition / SBR (settling)

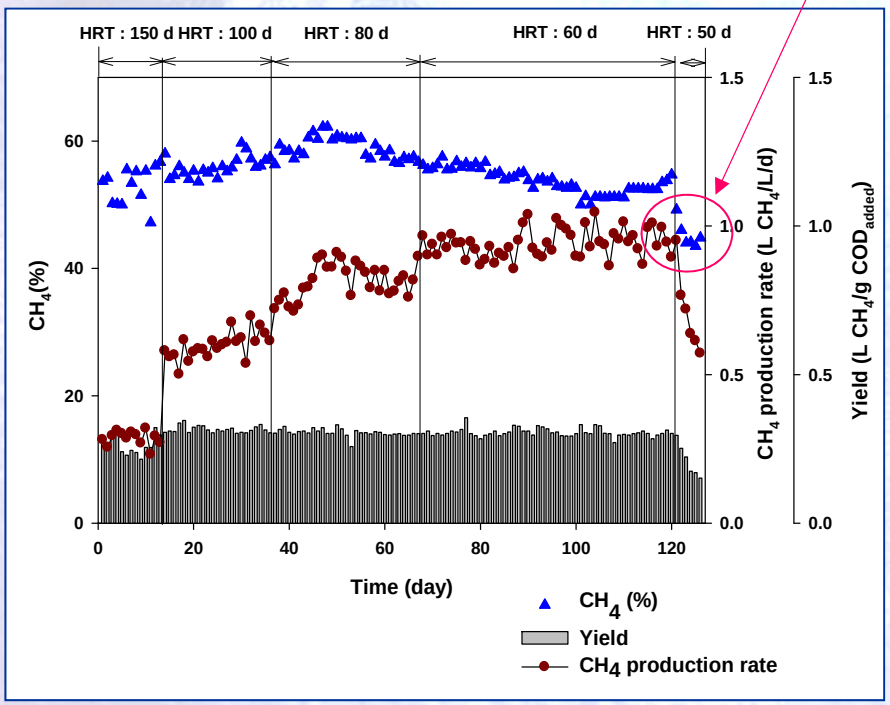
Trace element composition

Ni	Co
0.5 mg Ni/L	0.1 mg Co/L

Mesophilic vs. Thermophilic

Mesophilic condition

Failure at HRT 50 d

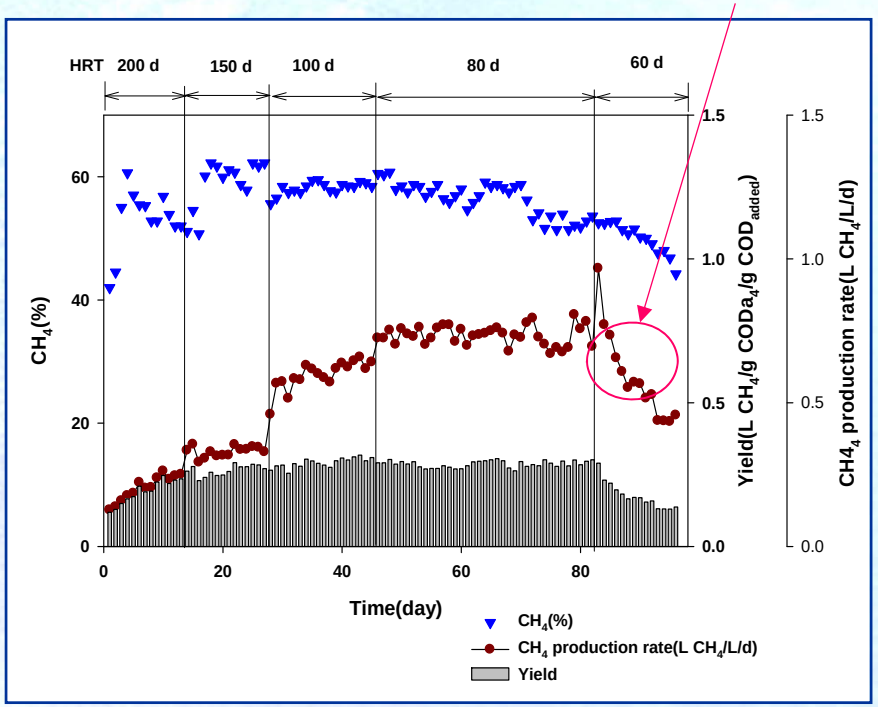


At HRT 60 d

: 0.94 L CH_4/L/d, 0.29 L CH_4/g COD_{added}

Thermophilic condition

Failure at HRT 60 d



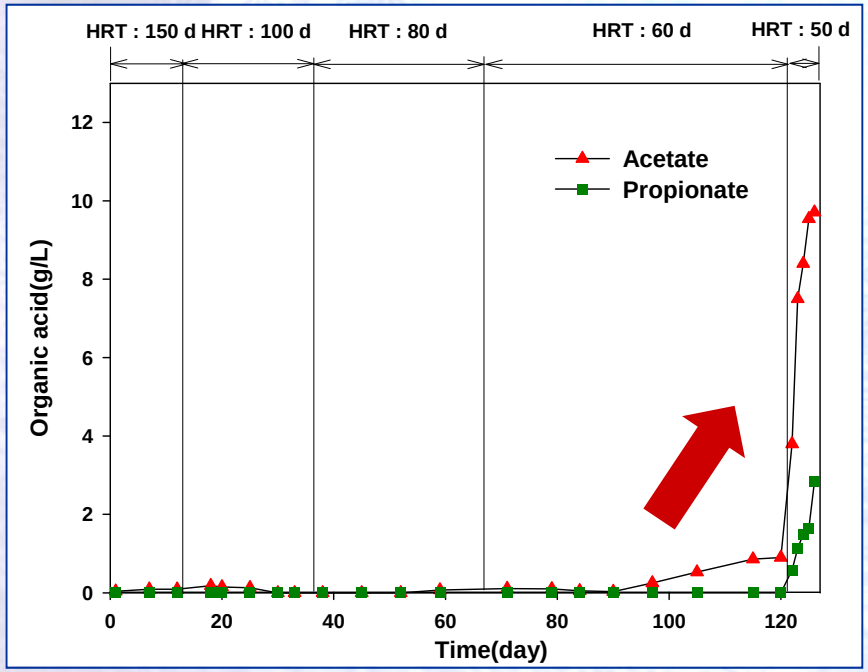
HRT 80 d

: 0.73 L CH_4/L/d, 0.29 m^3 CH_4/g COD_{added}

→ Organic acid accumulation and pH drop at failure

Organic acid accumulation at failure

Mesophilic condition

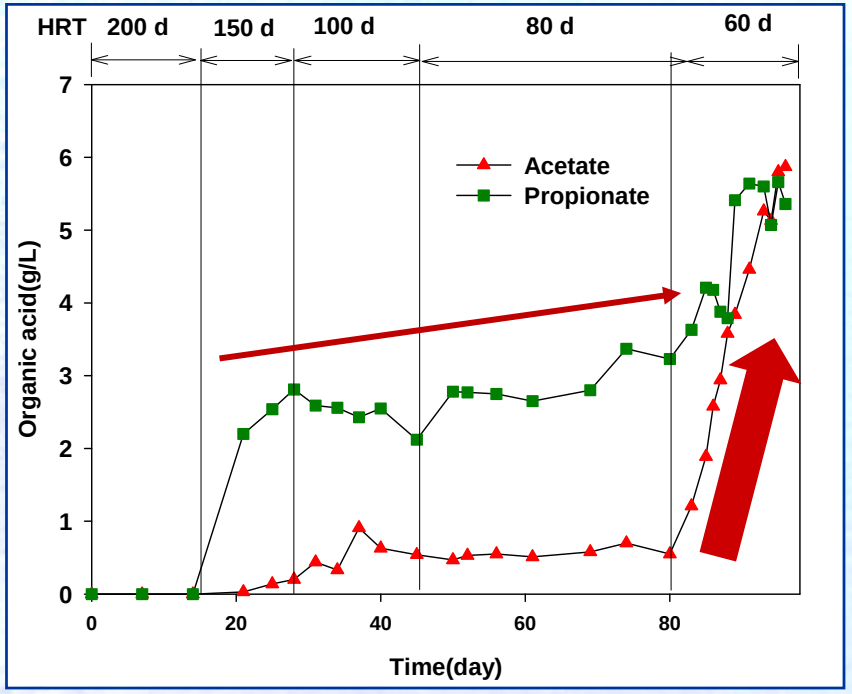


HRT (d) : 60 → 50

Acetate : 0.53 → 9.7 g COD/L

Propionate : 0.0 → 2.8 g COD/L

Thermophilic condition



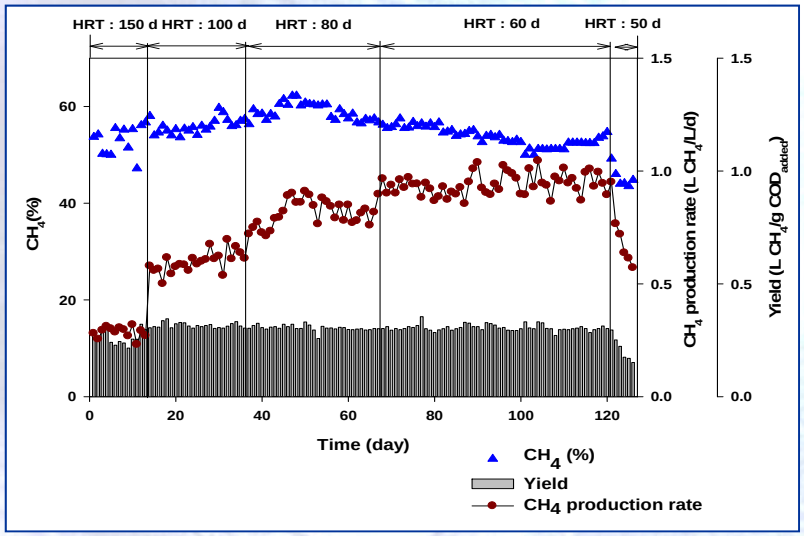
HRT (d) : 80 → 60

Acetate : 0.55 → 5.8 g COD/L

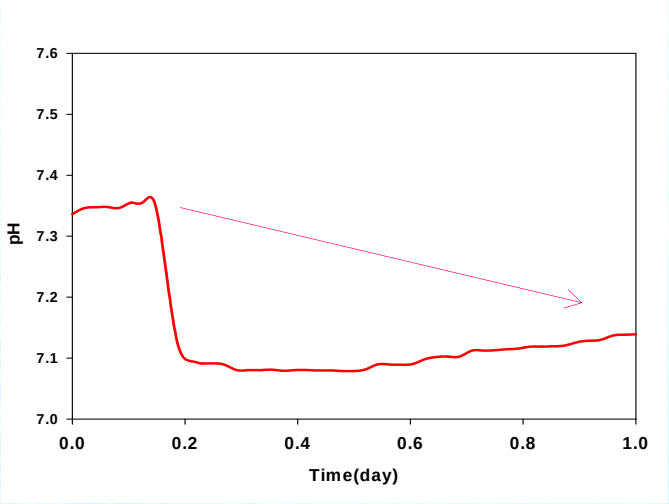
Propionate : 2.5 → 5.6 g COD/L

Effect of step-feeding

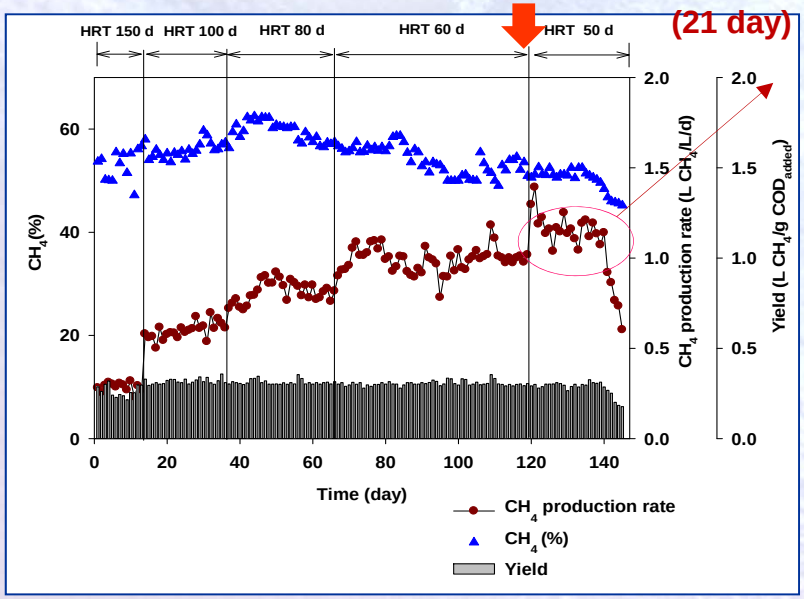
Failure at HRT 50 d f (1 day)



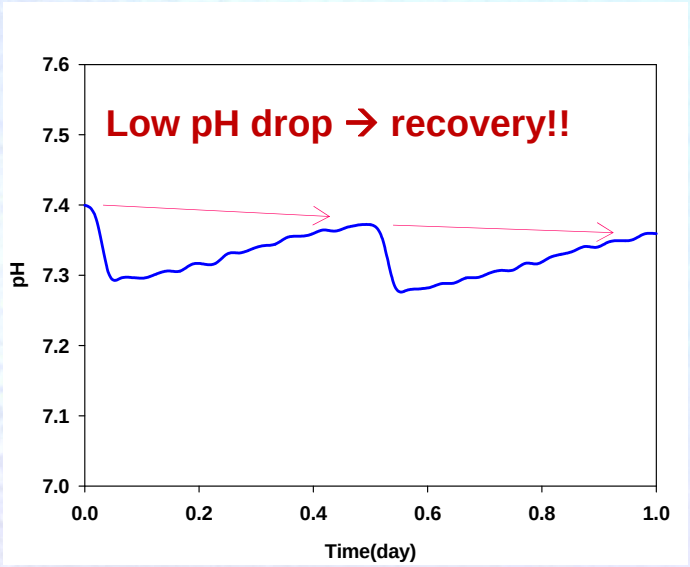
pH change (feeding)



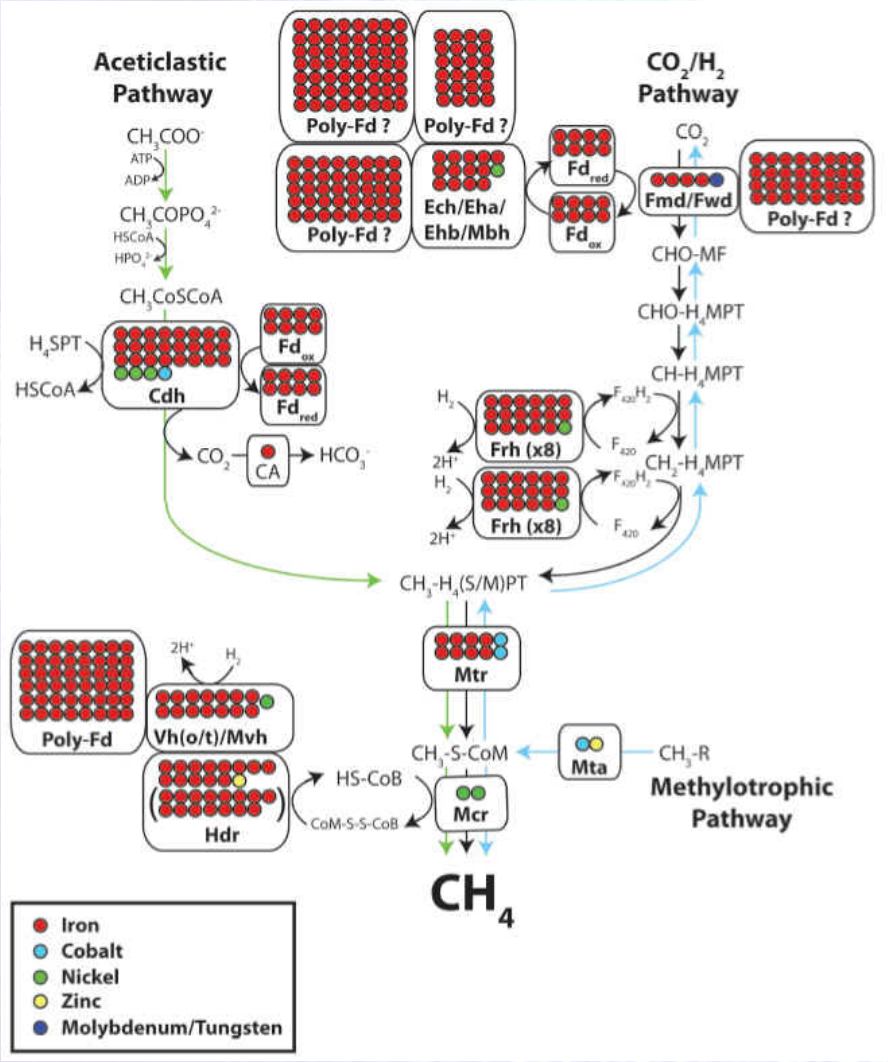
✓ Step – feeding **Failure at HRT 50 d (21 day)**



pH change (step-feeding)



Why trace metal ?



<Glass and Orphan, 2012>

Fe → Fe-S clusters and catalyst

Ni → Fe-S clusters and porphyrin

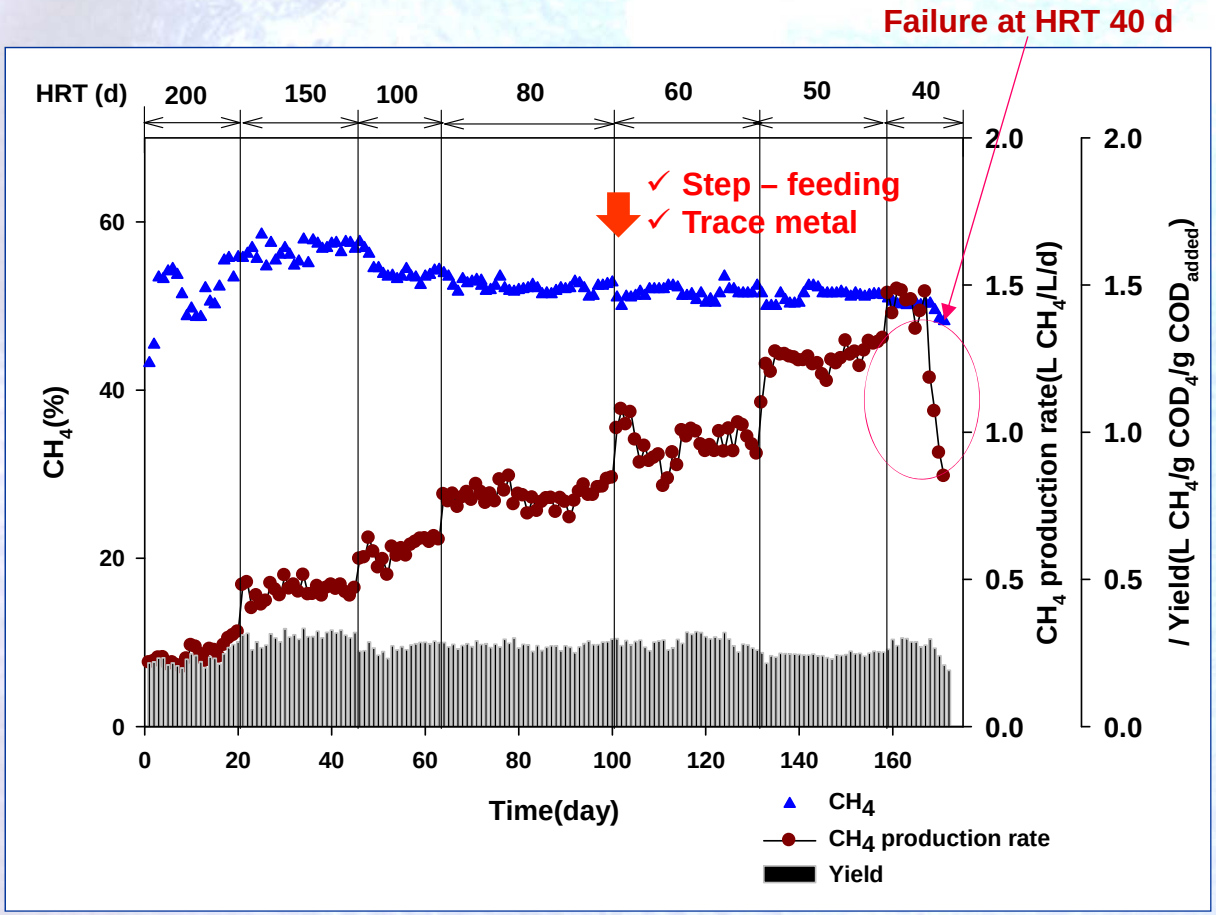
Co → cobamides

Trace metals	Trace metals in food waste (ug/kg)	Trace metals in ADS (ug/kg)	Trace metals addition used in this study (ug/kg_{in})
Ni	162.4	1,300	500
Co	9.3	106	200
Mo	152.0	834	0
Se	< 0.1	60	0
W	48.1	188	0
Fe	8,500	44,400	0

Analysis : ICP-MS, Korea Basic Science Institute (KBSI)

Proper conc.: Ni (0.02 ~ 1.0), Co (0.02 ~ 0.4)

Effect of trace metal addition



HRT 50 d –

1.31 L CH_4/L/d

0.30 L CH_4/g COD_{added}

51.2 % CH_4 (%)

HRT (d) : 50 → 40

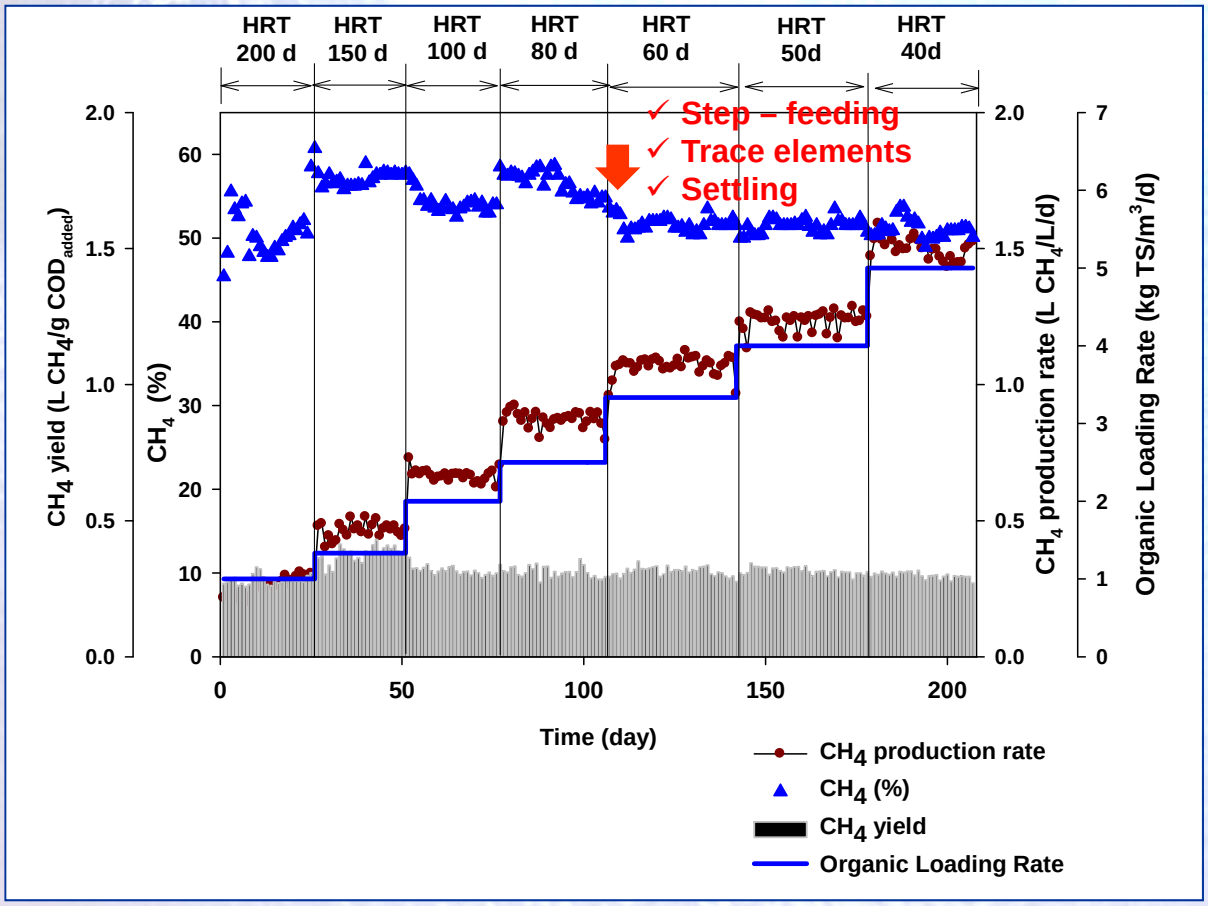
Acetate : 0.65 → 6.7 g COD/L

Propionate : 0.6 → 3.5 g COD/L

SBR performance (1)

Performance

(CH_4 (%), CH_4 production rate, yield)



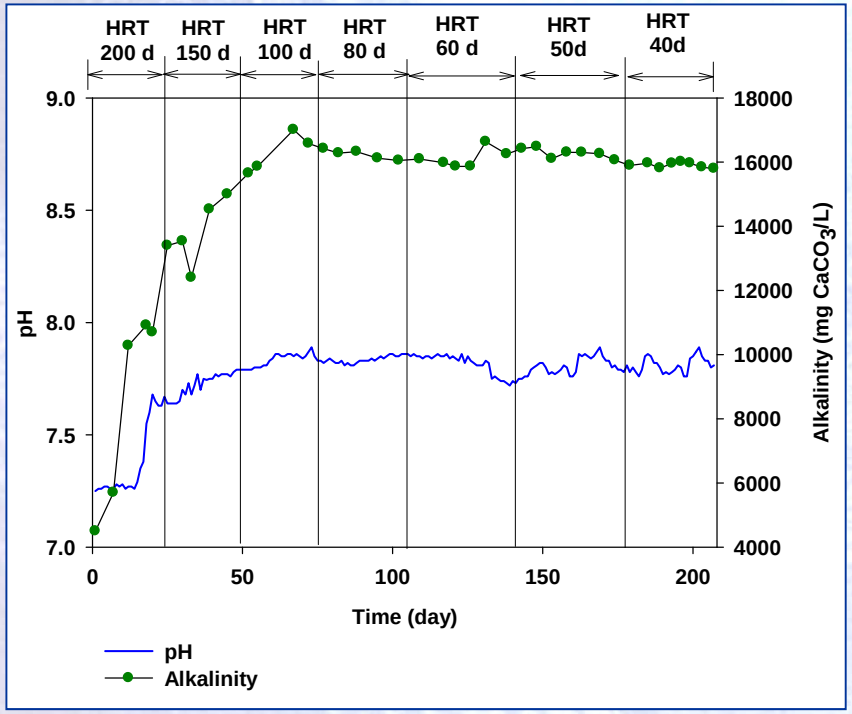
Sequencing Batch Reactor

- **Input (0.05 hr)**
- **Reaction (10 hr)**
- **Settling (1.9 hr)**
- **Discharge (0.05 hr)**

→ **HRT 40 d: 1.5 L CH_4/L/d, 0.30 L CH_4/g COD_{added}, 50.6 % CH_4 (%)**

SBR performance (2)

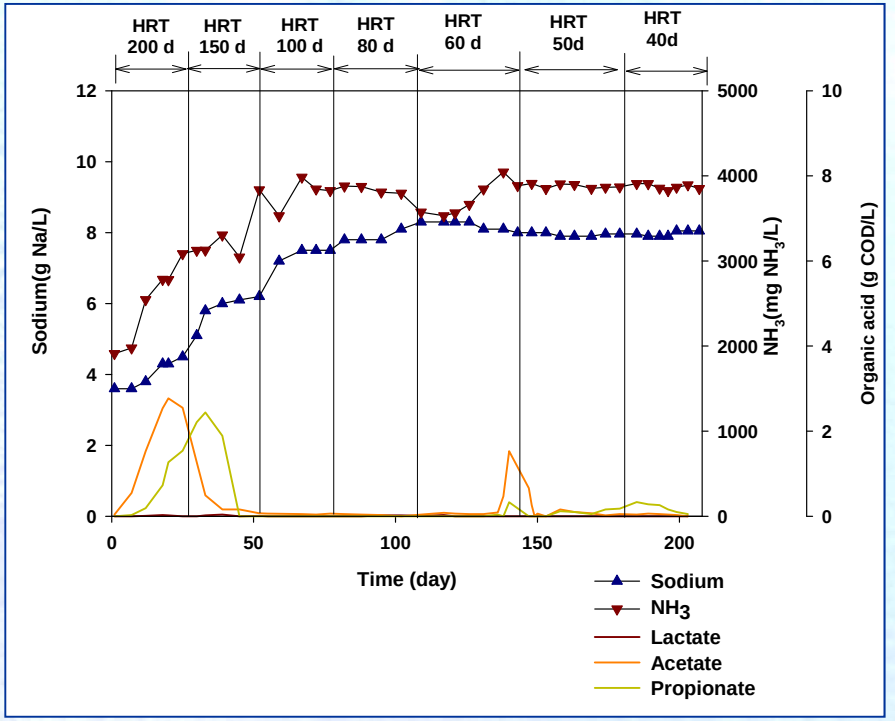
pH & Alkalinity



pH : 7.68 ~ 7.89

Alkalinity : average 16,500 mg $CaCO_3$/L

Na & NH_4^+ & organic acid



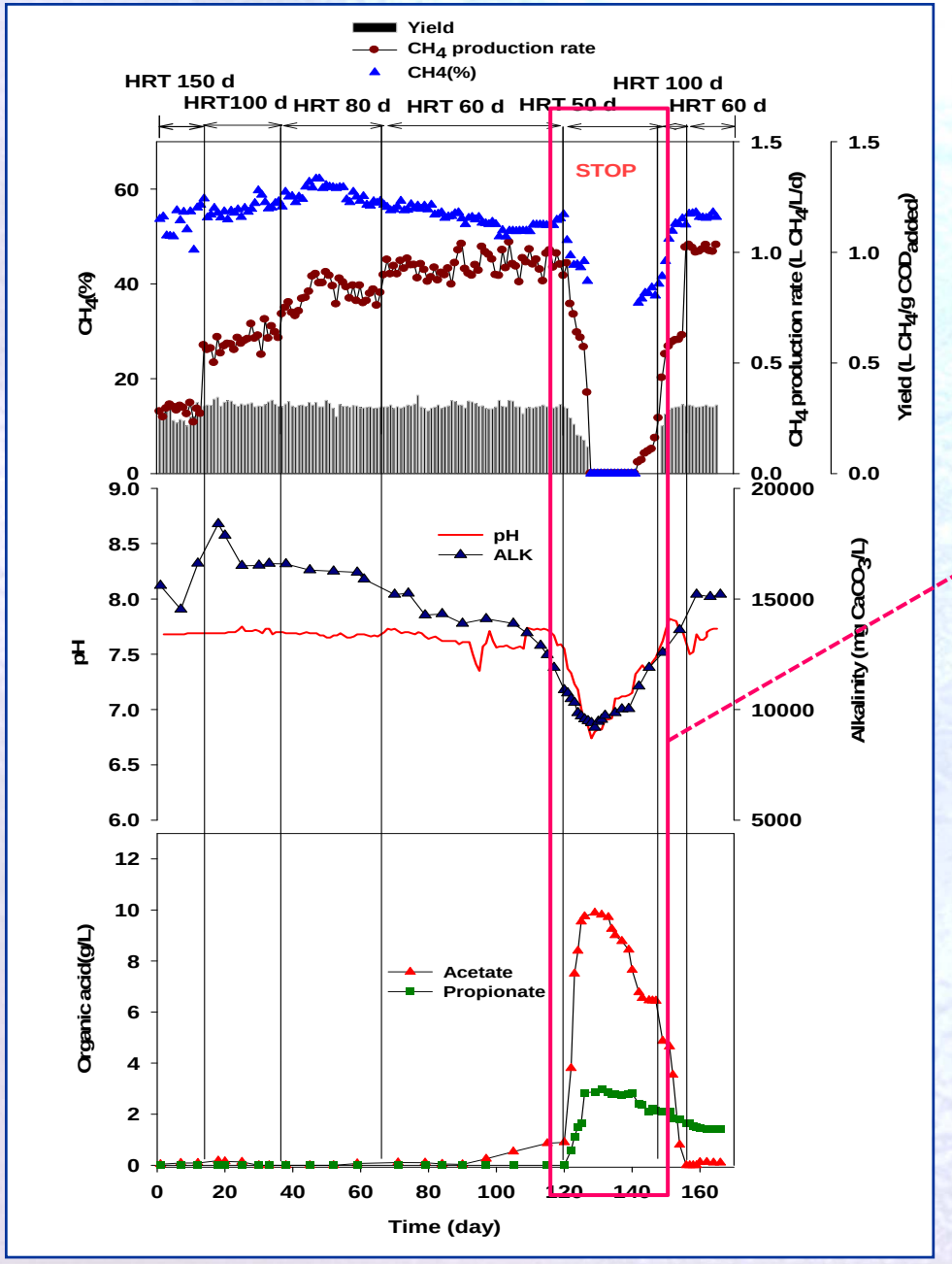
HRT 50 d → 40 d

Na conc. : 1.0 → 8.0 g Na/L → adaptation

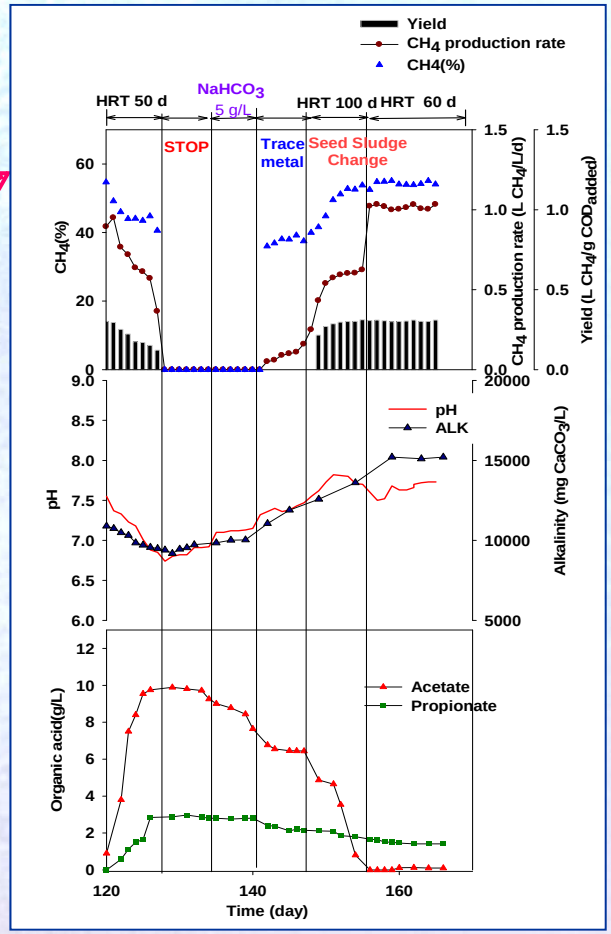
NH_3 conc. : 1.9 → 3.8 g NH_4^+/L → adaptation

Organic acid conc. : acetate < 1.5 g COD/L

Recovery strategy



- Natural recovery → fail
- pH increase (6.9 →7.1) by $NaHCO_3$ addition → acetate 9 to 7 g/L
- Trace metal addition → acetate 7.6 to 6.4 g/L
- Seed sludge 30% change → acetate 6.4 to 0.1 g/L within 5 days



Strategies for stable operation under high OLR

- Mesophilic vs. Thermophilic
- Step-feeding
- Trace metal addition
- SBR (Settling)

MPR (CH_4 production rate, L CH_4/L/d)

Yield (L CH_4/g COD_{added})

Salt toxicity

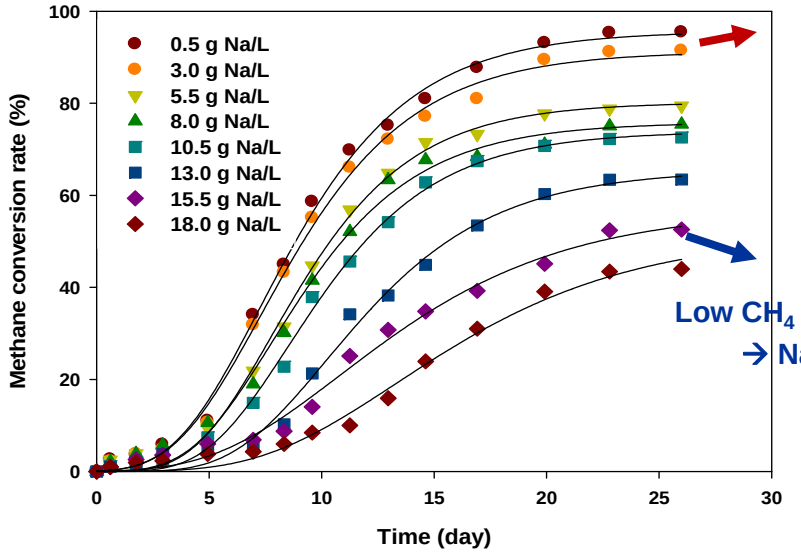
Materials and Methods

(shaking incubator)

- Temperature : 37 ℃
- Substrate: food waste (Na 0.5 g/L)
- Inoculum/Substrate ratio(g COD/g COD)=2.0
- Substrate conc.: 5 g COD/L
- Inoculum: Anaerobic Digested Sludge, 10 g COD/L
- Serum bottle: total 180 mL (100 mL)
- Na Conc.: 0.5~18 g Na/L addition (NaCl)
- Shaking condition: 250 rpm

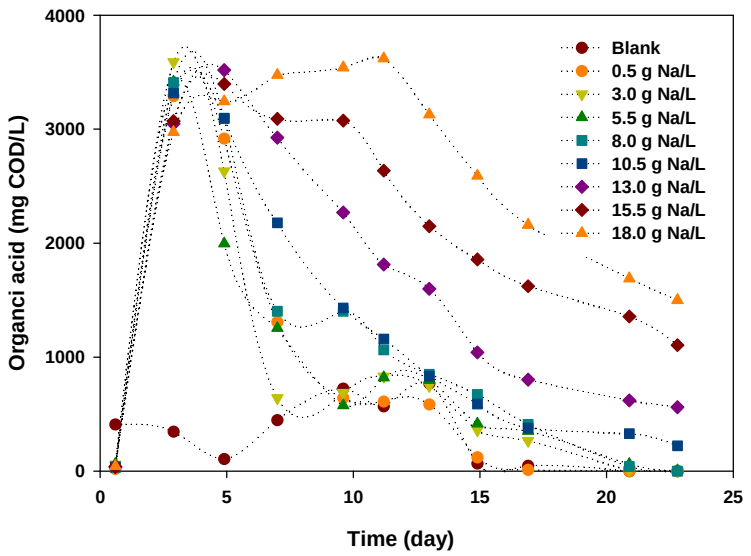
Cumulative CH_4 production

Maximum CH_4 conversion

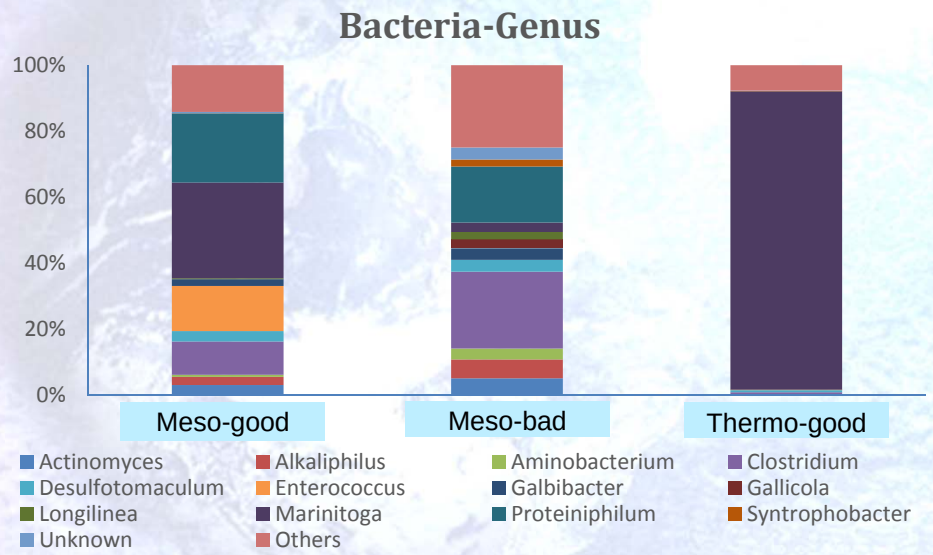


Low CH_4 conversion rate
→ Na inhibition

Organic acid profile



Microbial Community Analysis



Sample		Shannon
Bacteria	Meso-good	2.613669±0.055
	Meso-bad	3.687025±0.048078
	Thermo-good	0.645206±0.038926

- Meso-good

  : *Marinitoga* (some are mesophilic)

  Proteiniphilum (protein degradation, producing acetic and propionic acid)

  Enterococcus (lactic acid bacteria)

  Clostridium (carbohydrate degradation, acetate and butyrate producer)

- Meso-bad

  : *Clostridium*, *Proteiniphilum*

- Thermo-good

  (simple → related to low performance ?)

  : *Marinitoga* (thermophilic, salt-tolerant, SRB, carbohydrate & protein degradation, acetate, butyrate & valerate production)