Laboratory-scale Investigation of Anaerobic Sludge Digestion Process

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DSD R&D Forum 2012
Wastewater treatment session

28 Nov 2012

Outline

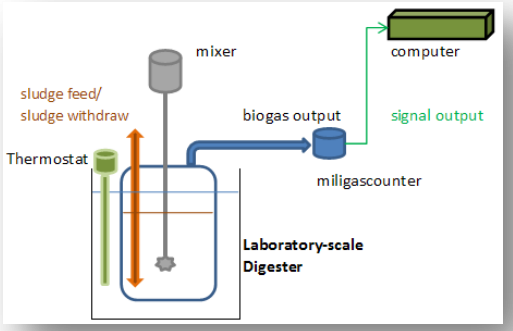
- Findings
- Sludge treatment (general)
- Anaerobic digestion (AD) of sewage sludge
  - Hong Kong
- Sludge handling in Shatin STW
- Factors affecting AD
- Two Lab-scale experiments
- Conclusions

Major findings

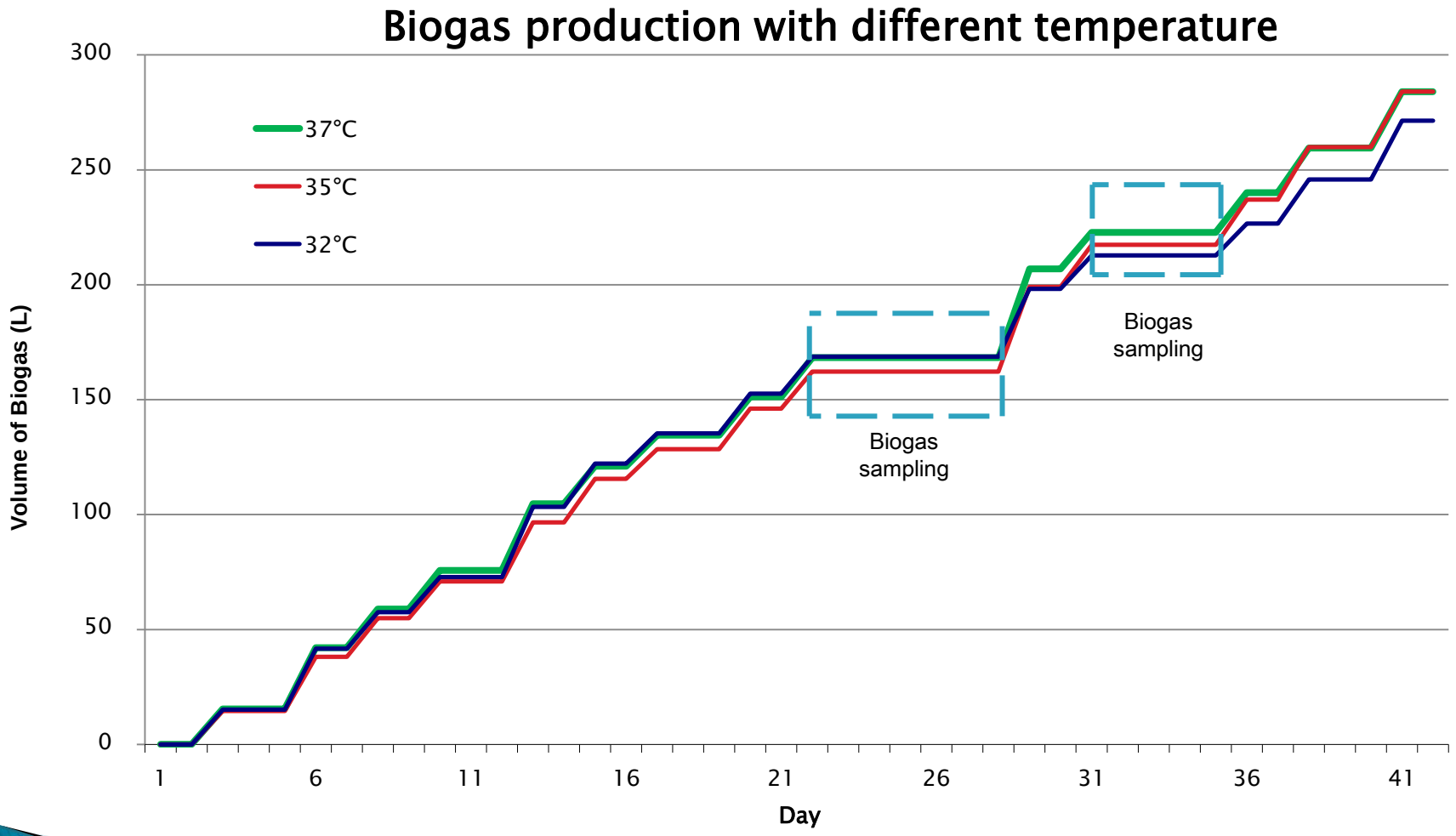
VSR = volatile solids reduction

- Lab-scale digesters to provide useful side-by-side comparison
- 3-temp experiment (32, 35, 37°C):
  - 35~37°C. 32°C (ave) still very acceptable.
  - Similar VSR%, comparable Biogas production
  - Healthy process
- 3-HRT experiment (12d, 16d, 20d):
  - Biogas production 16d (**95%**) & 12d (**81%**) of 20d.
  - Similar VSR%.
  - Healthy process

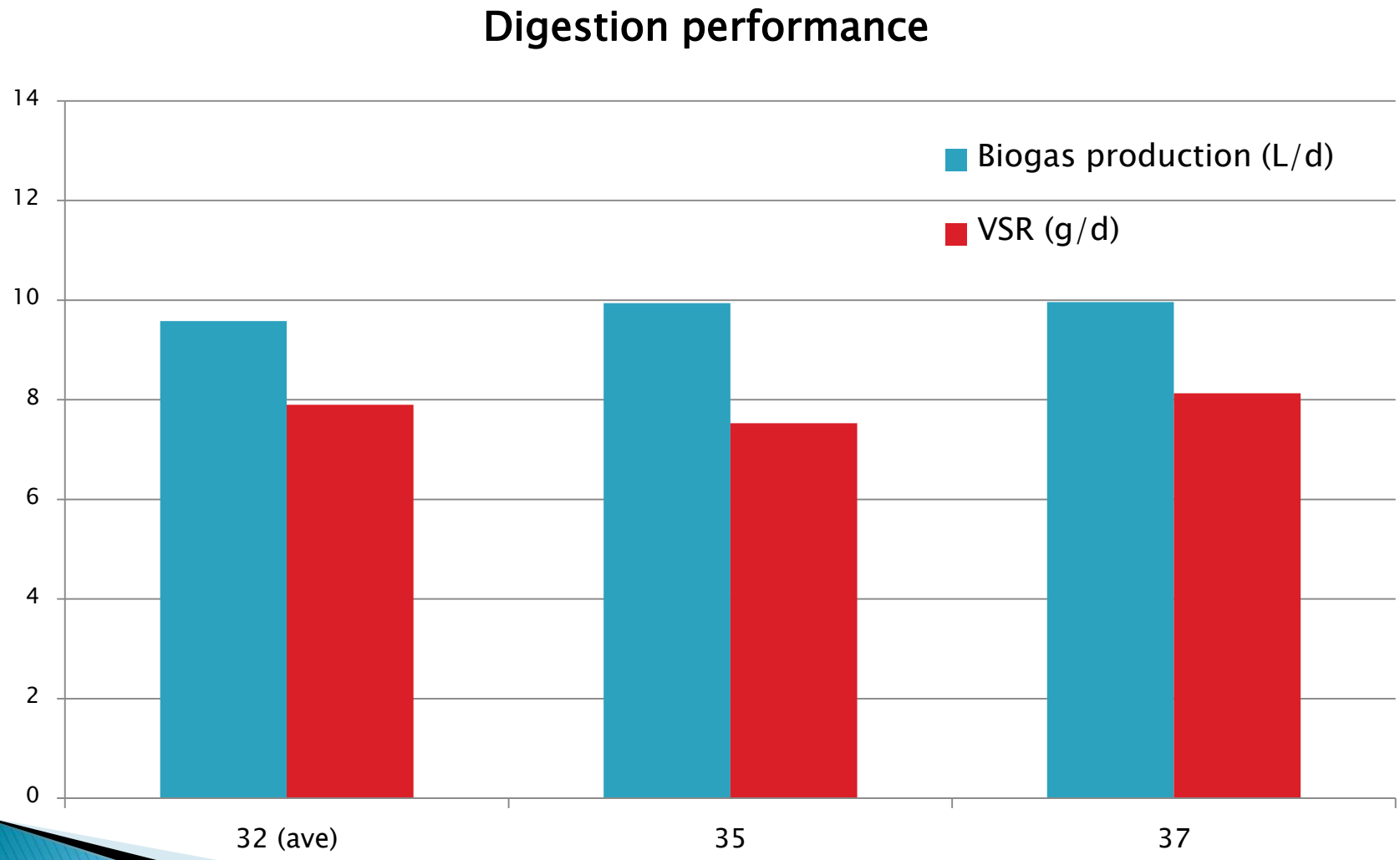
HRT = hydraulic retention time
= Volume/Flow



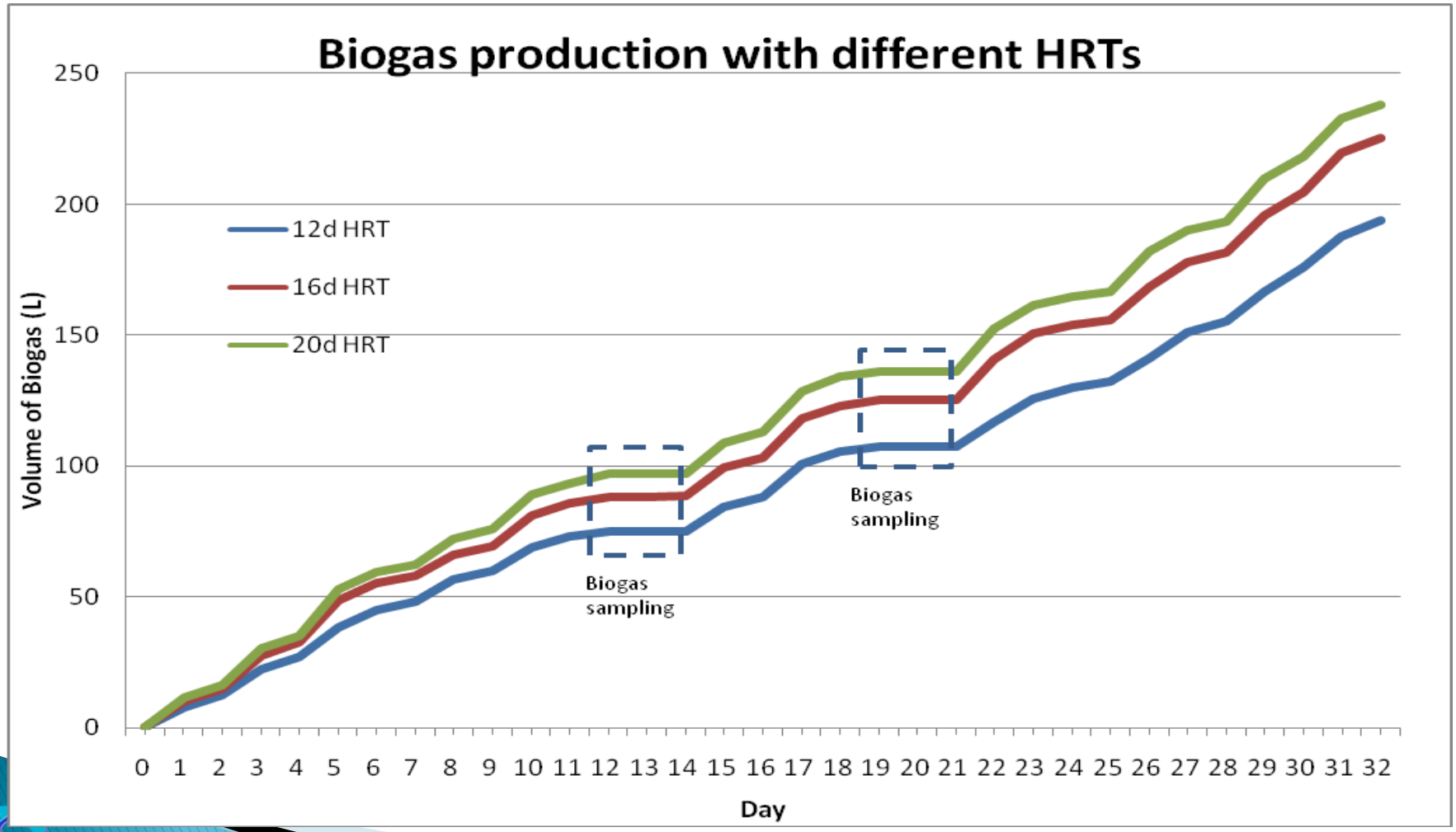
Expt 1 (3-temp)


Biogas production with different temperature
300
250
200
150
100
50
0
Volume of Biogas (L)
37°C
35°C
32°C
Biogas sampling
Biogas sampling
1
6
11
16
21
26
31
36
41
Day

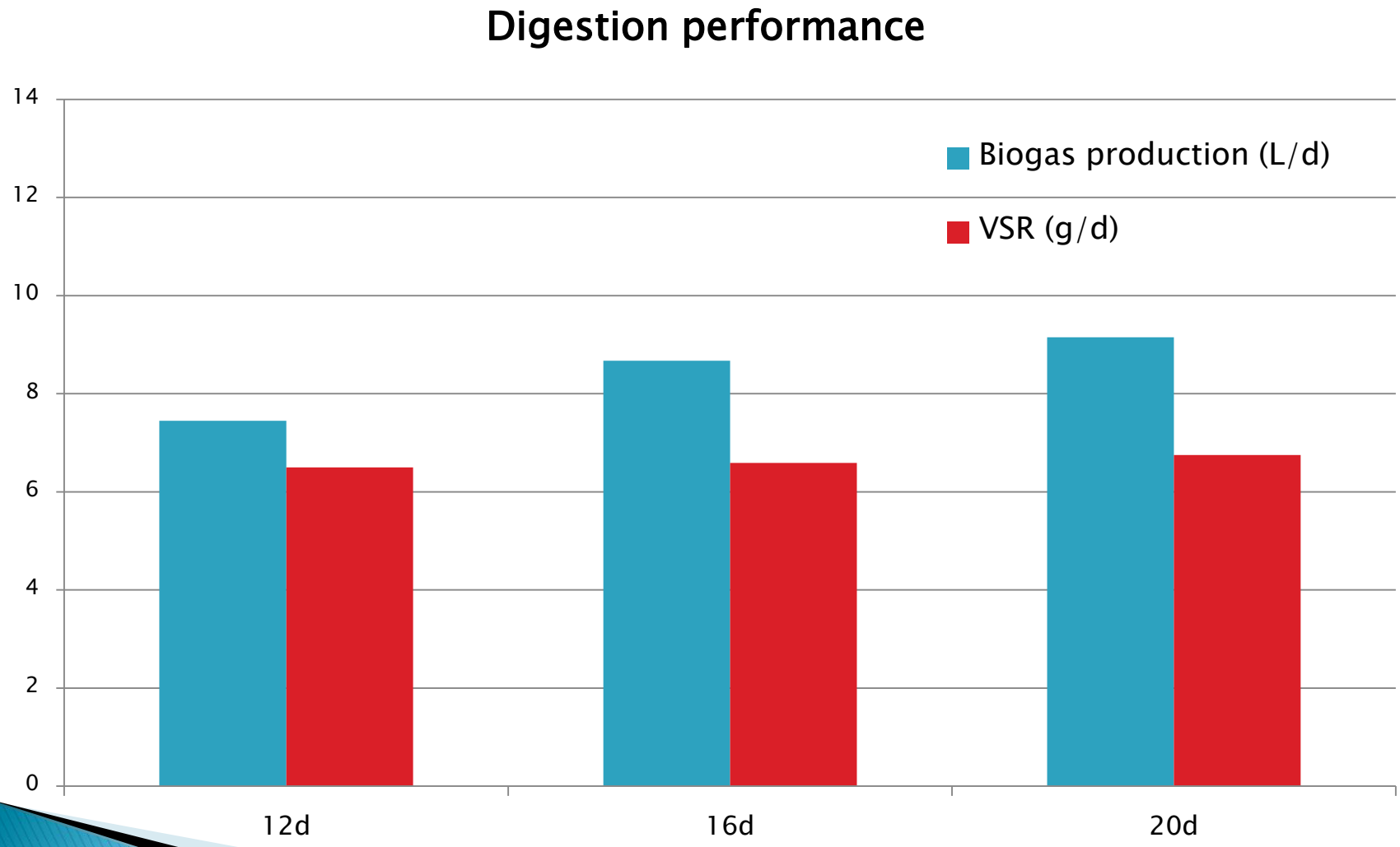
Expt 1 (3-temp)


Digestion performance
14
12
10
8
6
4
2
0
Biogas production (L/d)
VSR (g/d)
32 (ave)
35
37

Expt 2 (3-HRT)

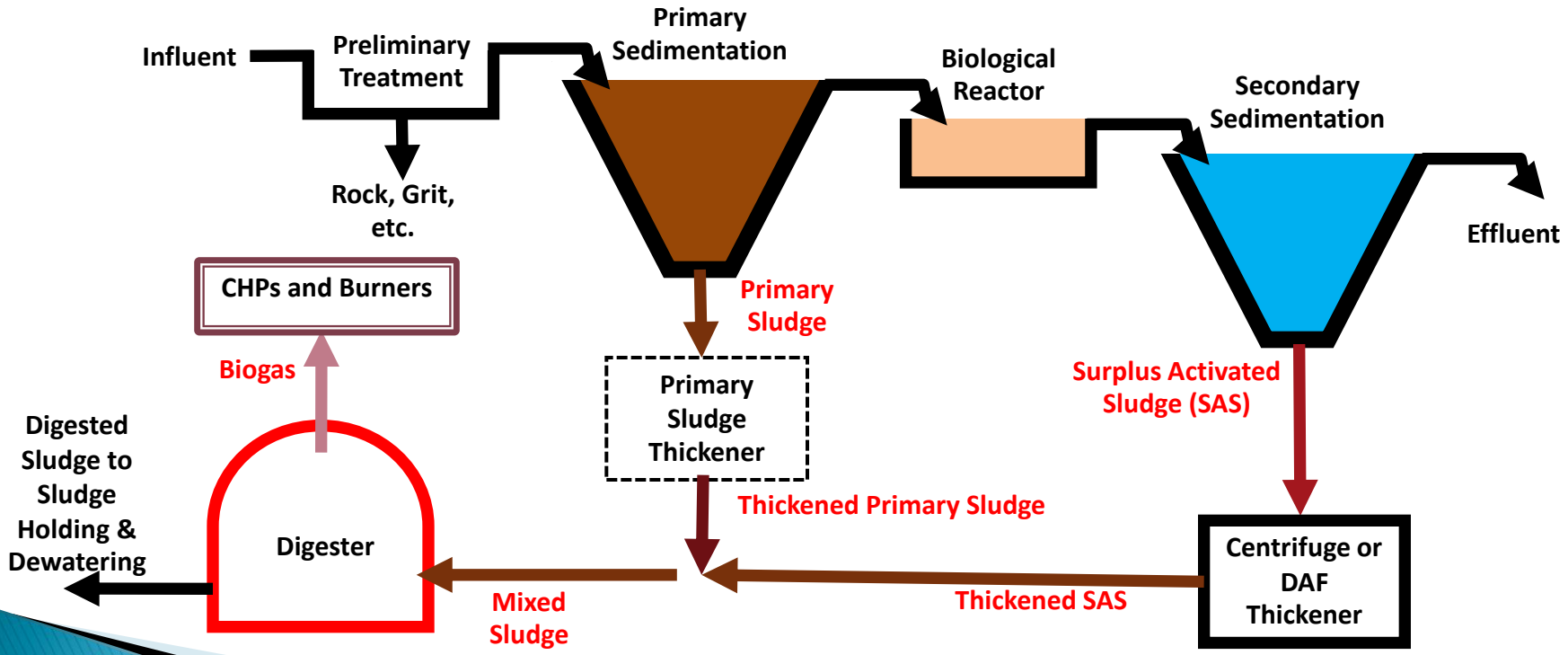

Biogas production with different HRTs
Volume of Biogas (L)
250
200
150
100
50
0
12d HRT
16d HRT
20d HRT
Biogas sampling
Biogas sampling
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32
Day

Expt 2 (3-HRT)


Digestion performance
14
12
10
8
6
4
2
0
Biogas production (L/d)
VSR (g/d)
12d
16d
20d

Overview – Sludge treatment

- Sludge (Primary + SAS) produced during sewage treatment



Sludge digestion process

- Sludge handling processes
  - Sludge thickening
  - Sludge digestion
  - Sludge dewatering
  - Landfill disposal / Incineration

- Purposes of Sludge Digestion
  - Stabilize
  - Organic matter destruction
  - (Anaerobic) **Biogas** production

Sludge Digestion Processes in Hong Kong

- **Anaerobic** Sludge Digestion
  - Shatin STW (14)
  - Tai Po STW (8)
  - Shek Wu Hui STW (4)
  - Yuen Long STW (4)

- Aerobic Sludge Digestion
  - Sai Kung STW

Biogas as renewable energy

- CHP in Tai Po STW
  - 625 + 630* kW
- CHP in Shek Wu Hui STW
  - 330 + 635 kW
- Dual-fuel generator and CHP in Shatin STW
  - (4) 1.12 MW on diesel + biogas mode
  - 1400 kW CHP

Incentives to improve AD

- To improve biogas production
- To improve organic matter destruction
  - (As volatile solids reduction)

- Full-scale AD experiment is difficult
- Laboratory-scale AD ??

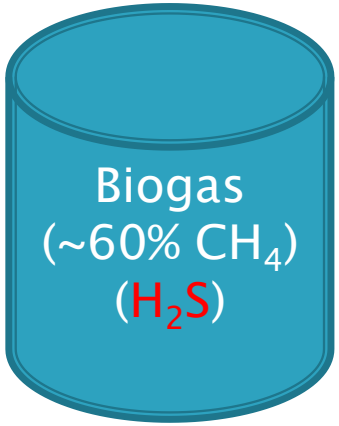
Background of sludge AD in Shatin STW

- Shatin STW
  - Sewage flow: 226,000 m^3/day
  - Feed sludge to digester (PS, TSAS, scum): 1,750 m^3/d
  - Sludge cake: 114 tonne/d (31% dryness)
- Mesophilic (~35°C) reaction
- Design HRT ~20d
  - Digester volume 2,960m^3 (×8), 3,420m^3 (×6)
- Biogas as renewable energy
  - Dual-fuel generator & CHP

What's special about sludge treatment in Shatin STW?

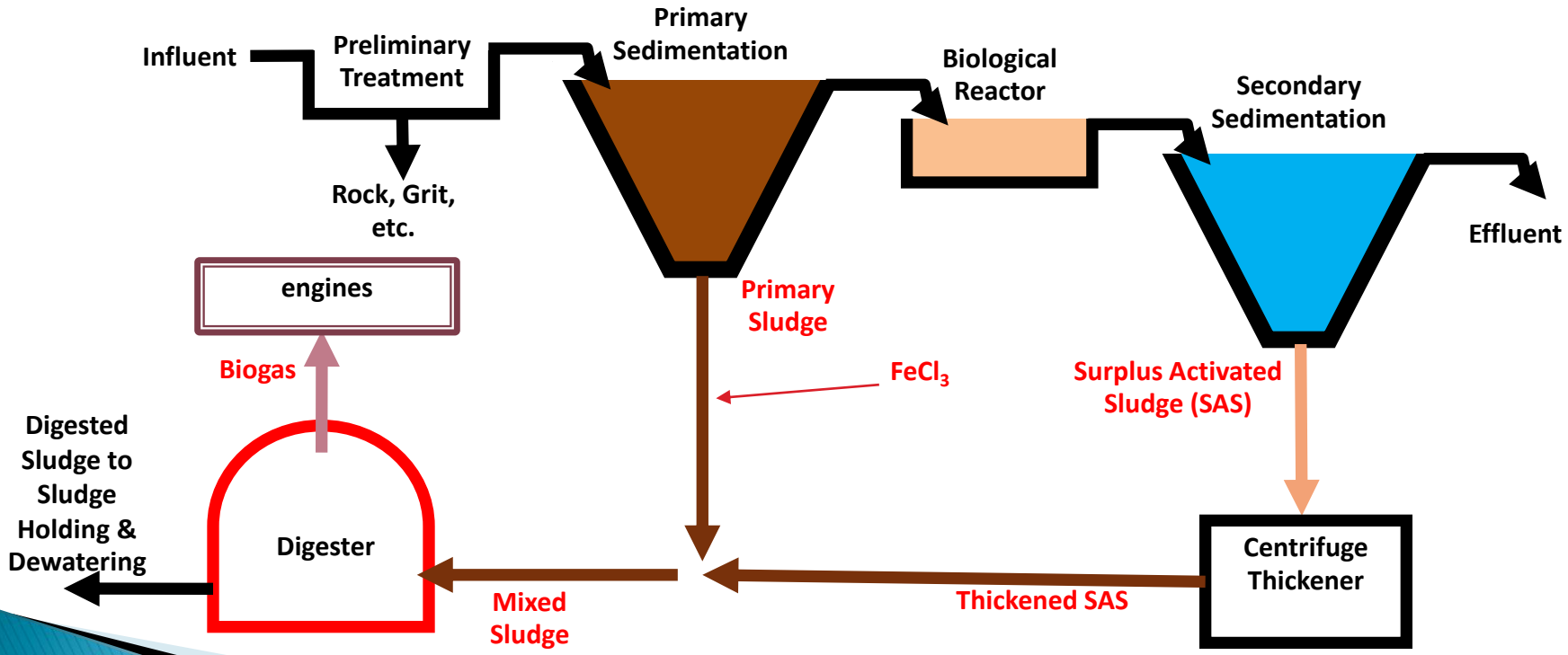
- Saline sewage
  - Higher in SO_4^{2-} (seawater)
  - Anaerobic environment: $SO_4^{2-} \rightarrow$ sulfide

- In-pipe $FeCl_3$ dosing in PS
  - To suppress H_2S in biogas



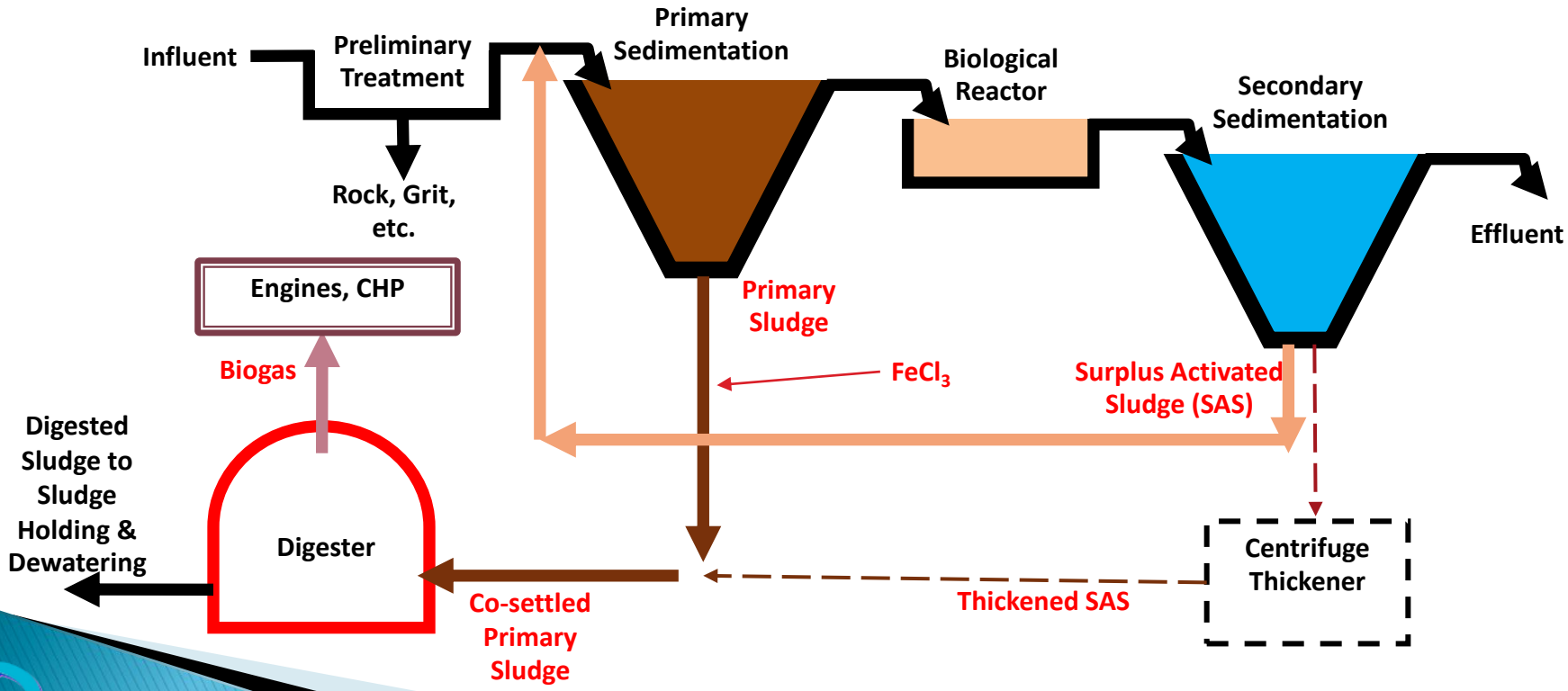
Sludge treatment in Shatin (1)

- More conventional sludge handling

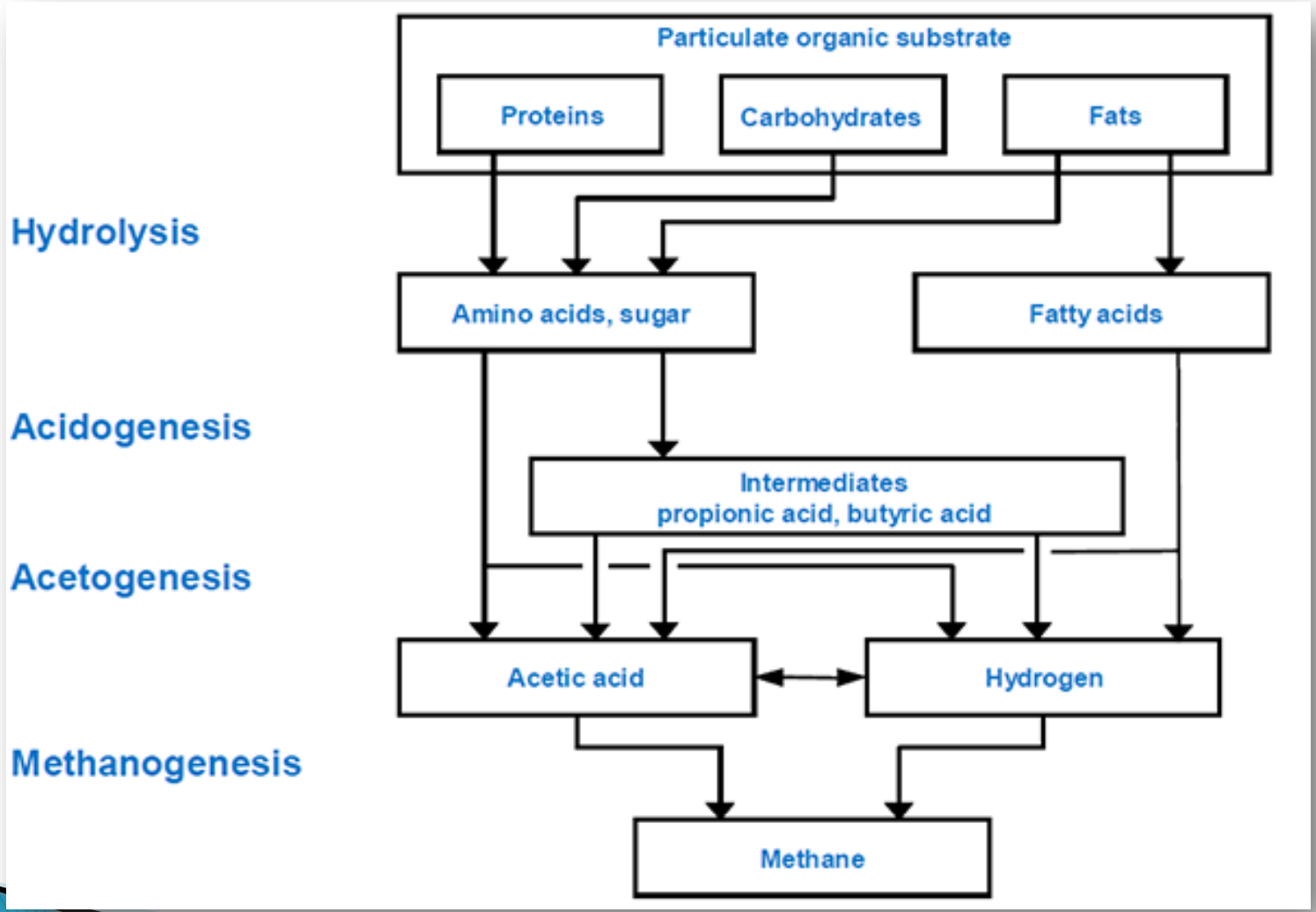


Sludge treatment in Shatin (2)

- Sludge co-settling



Acidogenesis & Methanogenesis



Factors affecting Sludge AD process

- Physical, chemical and biological factors:
  - Digestion temperature (mesophilic: typical 35-37°C)
  - Digester volume / HRT
  - Sludge composition
  - Organic loading
  - Alkalinity (total ALK 2000~5000)
  - pH
  - Chemical dosing
  - Presence of inhibitors (heavy metals, sulfide, etc.)
  - Mixing

DSD in-house R&D Study – Objectives

- To evaluate the feasibility of using laboratory-scale reactor to mimic full-scale anaerobic digestion (AD) process, and

- To assess the effectiveness of digestion process in Shatin STW
  - At three different digestion temperatures and
  - At three different hydraulic retention times

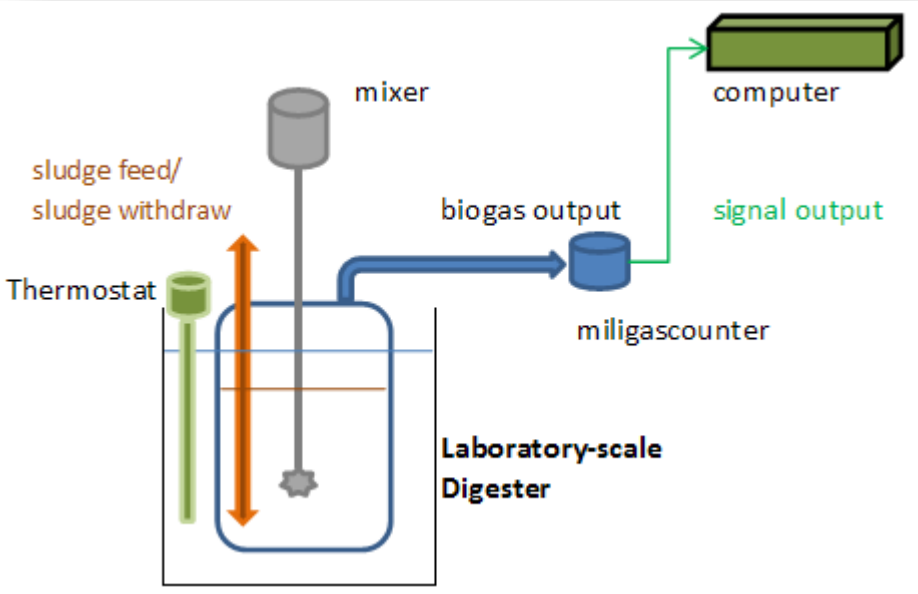
Laboratory-scale sludge AD process

- Factors to be examined:
  - **Digestion temperature**, digester volume, **HRT**, sludge composition, organic loading, pH, chemical dosing, presence of inhibitors, mixing.
- Three-temperature experiment
  - At 32, 35 & 37°C.
- Three-HRT experiment
  - At 12d, 16d & 20d.

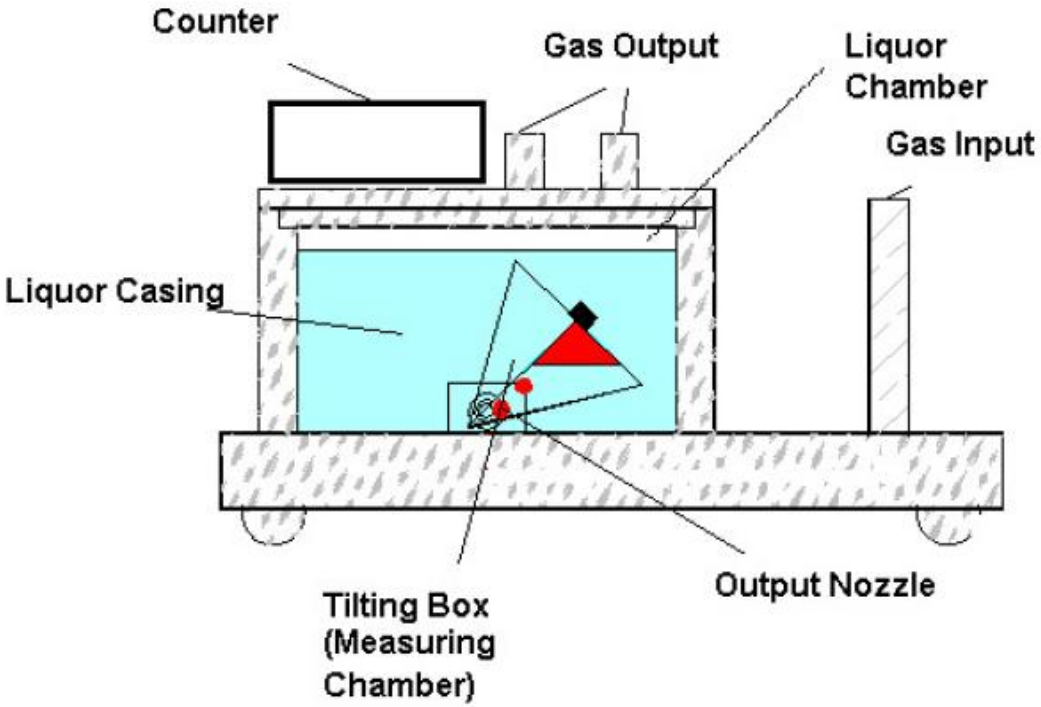
Methodology

- Experiment in (Shatin) Central Laboratory
- Equipment:
  - Laboratory-scale digester:
    - glass reactor (>10L)
    - air-tight mechanical mixer
    - water-bath
    - MilligasCounter®
- 3 digesters (1 Control + 2 Test systems)

Shatin Central Laboratory – Experimental setup



- MilligasCounter®
  - (Model MGC-10 from Ritter)



Measures of effectiveness of AD

- Feed sludge vs Digested sludge
  - VSR
- Biogas production
- Digested sludge
  - pH, VFA, alkalinity

- Operating parameters
  - Temperature, sludge feed (TS%, VS%)

Laboratory-scale sludge AD process (Expt 1)

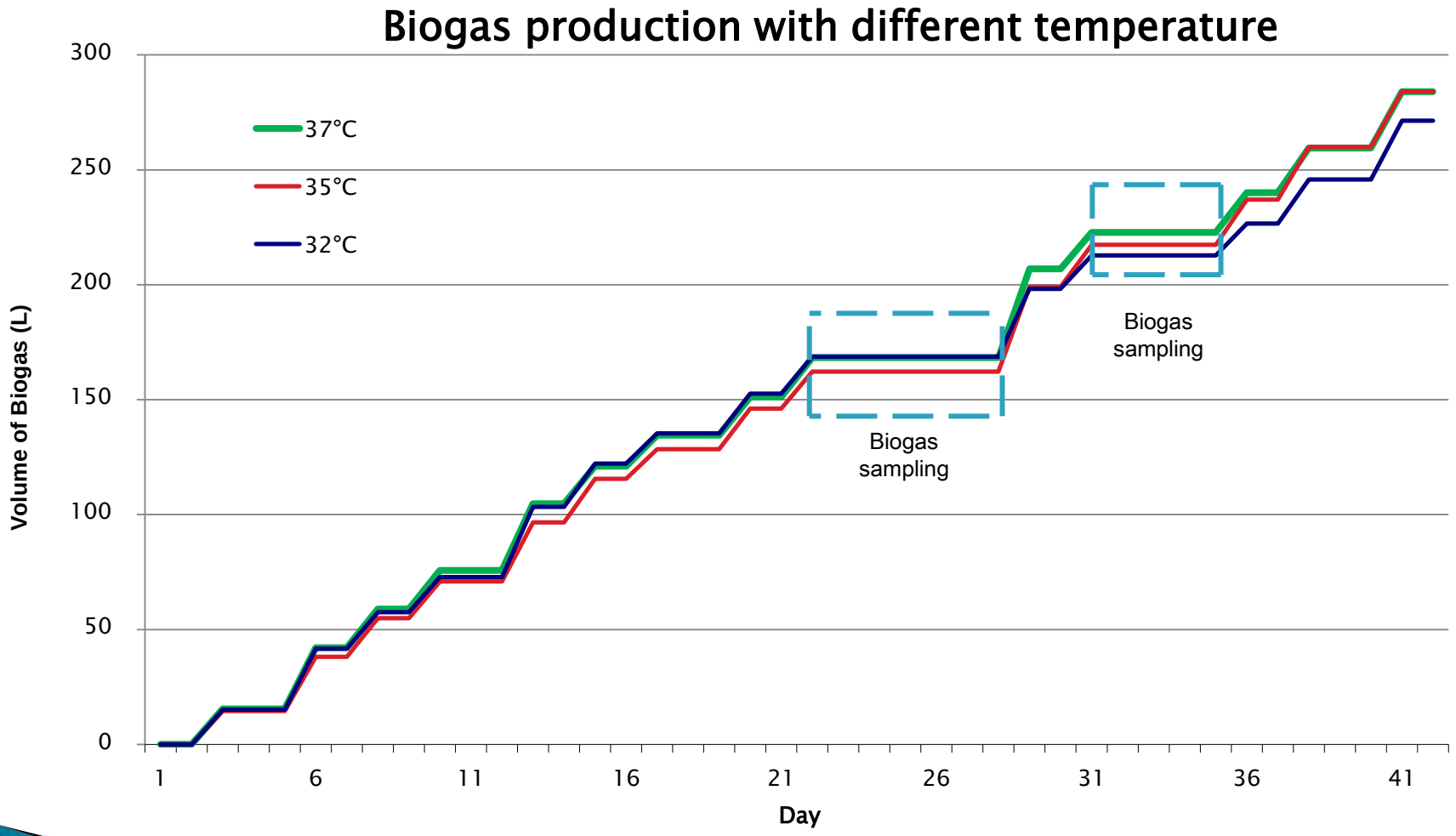
- Factors to be examined:
  - **Digestion temperature**, digester volume, **HRT**, sludge composition, organic loading, pH, chemical dosing, presence of inhibitors, mixing.
- Three-temperature experiment
  - At 32, 35 & 37°C
- Three-HRT experiment
  - At 12d, 16d & 20d

Experiment 1 (3-temperature)

- 3-temperature: 32, **35**, 37 ^{o}C
- Aims
  - How detrimental low-temp digestion is?
  - Is 37 ^{o}C better than 35 ^{o}C ?

At HRT=**16d**, **same feed** with PS:TSAS in 2.8:1.0 ratio, 1.8 mL $FeCl_3$ per liter of sludge. (Effective sludge volume of 8L and average feed of 0.5L per day)

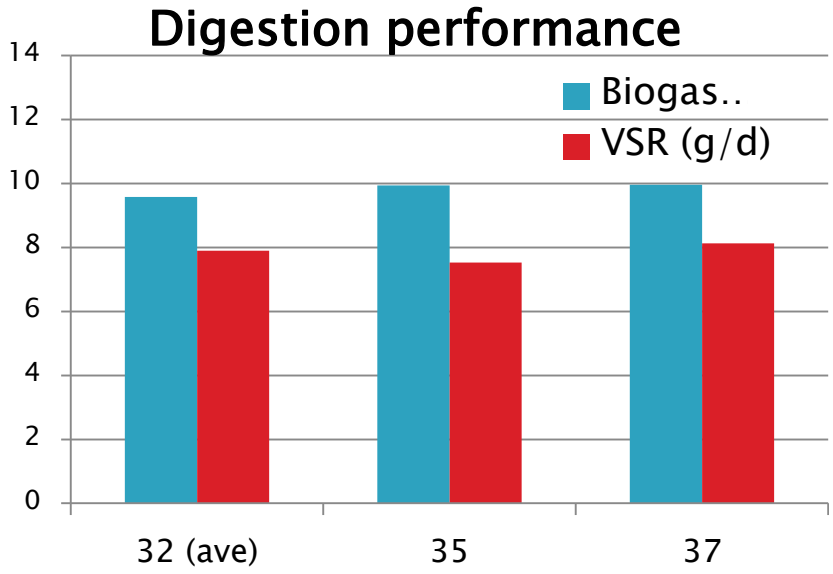
Expt 1 (3-temp)


Biogas production with different temperature
300
250
200
150
100
50
0
Volume of Biogas (L)
37°C
35°C
32°C
Biogas sampling
Biogas sampling
1
6
11
16
21
26
31
36
41
Day

Expt 1 (3-temp)

Temp (°C)	**VSR** (g/d)	**Biogas** production (L/d)	*Specific rate* Biogas produced/VM destroyed (**m^3/kg** reduced)	VSR (%)
32	7.90	**9.58**	1.21	52
35	7.53	**9.94**	1.32	50
37	8.13	**9.96**	1.22	54

Temp (°C)	pH	TS (%)	VS (%)
32	6.7	2.9	48
35	6.7	2.9	47
37	6.7	3.0	46
Feed Sludge	5.8	4.3	66



Expt 1 (3-temp)

Temperature (^oC)	Alkalinity (mg $CaCO_3$/L)	VFA (mg/L)	VFA/Alkalinity Ratio
32	3787	632	0.17
35	3827	716	0.19
37	3880	468	0.12

Digestion temperature (^oC)	Biogas composition (CH_4%)
32	66.2
35	63.6
37	65.2
Typical range	65-70%

Summary of Expt #1

- Shatin (saline) sewage sludge
- Digestion performance at 32°C (ave) was good
  - In digested sludge (TS%, VS%)
  - In %VSR
  - In VFA & Alkalinity
  - In biogas production
  - CH_4 content

- Digestion at 37°C ~ 35°C

Laboratory-scale sludge AD process (Expt 2)

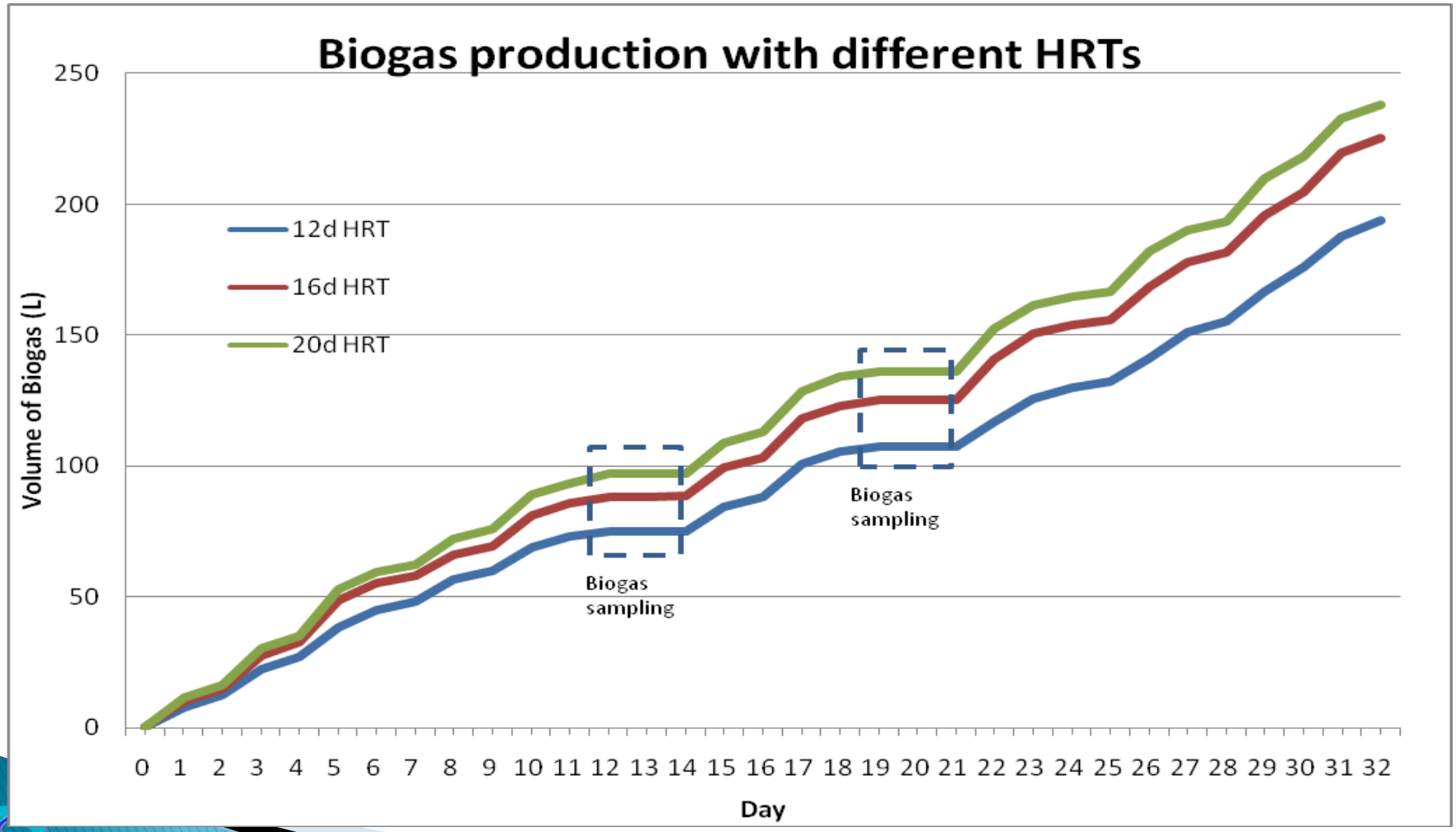
- Factors to be examined:
  - **Digestion temperature**, digester volume, **HRT**, sludge composition, organic loading, pH, chemical dosing, presence of inhibitors, mixing.
- Three-temperature experiment
  - At 32, 35 & 37°C
- Three-HRT experiment
  - At 12d, 16d & 20d

Experiment 2 (3-HRT)

- 3-HRT: 12d, 16d, 20d
- Aims
  - Effects of shorter HRT?

At **35°C**, **same feed** with <u>combined PS</u>, 1.8 mL $FeCl_3$ per liter of sludge. (average feed of 0.5L per day, at effective sludge volumes of 6L, 8L and 10L respectively)

Expt 2 (3-HRT)


Biogas production with different HRTs
Volume of Biogas (L)
250
200
150
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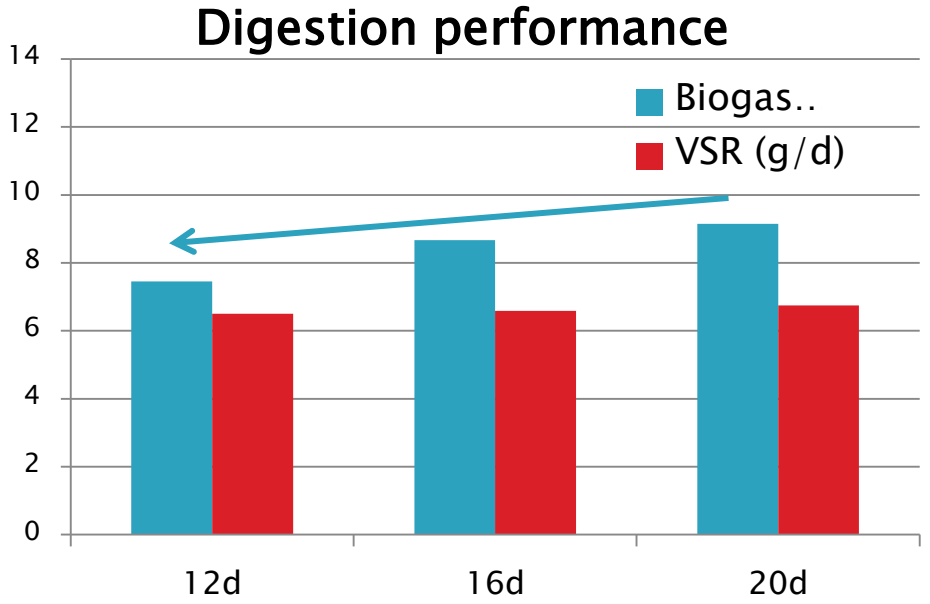
0
12d HRT
16d HRT
20d HRT
Biogas sampling
Biogas sampling
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32
Day

Expt 2 (3-HRT)

HRT (d)	**VSR** (g/d)	**Biogas** production (L/d)	Relative production to 20d HRT (%)	*Specific rate* Biogas produced/VM destroyed (**m^3/kg** reduced)	VSR (%)
12	6.50	7.45	**81%**	1.15	**54%**
16	6.59	8.67	**95%**	1.32	**54%**
20	6.75	9.15	(100%)	1.36	**56%**

HRT (d)	pH	TS (%)	VS (%)
12	6.6	2.5	45
16	6.7	2.5	44
20	6.7	2.5	43
Feed Sludge	5.6	4.0	64



Expt 2 (3-HRT)

HRT (d)	Alkalinity (mg $CaCO_3$/L)	VFA (mg/L)	VFA/Alkalinity Ratio
12	3290	398	0.10
16	3772	477	0.13
20	3497	424	0.12

HRT (day)	Biogas composition (CH_4%)
12	64.1
16	63.9
20	63.5
Typical range	65-70%

Summary of Expt #2

- Shatin (saline). Co-settled primary sludge
- Noticeable change in digestion performance with HRT: 20d $\rightarrow$ 16d $\rightarrow$ 12d
  - In Biogas production
- The drop 20d $\rightarrow$ 16d was minor

Compare with full-scale digestion

	Full-scale Shatin STW (Apr-May 2011)	Lab-scale Experiment 1	Full-scale Shatin STW (Sep-Oct 2011)	Lab-scale Experiment 2
HRT	10.7d	16d	10.6d	12,16,20d
%VSR	44%	50-54%	47%	54-56%
Sp. Biogas production (m^3/kg reduced)	0.60	1.2-1.3	0.64	1.2-1.4
CH_4 (%vol)	61%	64-66%	63%	64%

- We *cannot* conclude that laboratory-scale digestion can *fully* mimic full-scale digestion.

Conclusions

- Lab-scale digesters provides useful side-by-side comparison

- 3-temp experiment (32, 35, 37°C):
  - Similar VSR%, comparable Biogas production
  - Healthy AD process
  - 35~37°C. 32°C still very acceptable.

- 3-HRT experiment (12d, 16d, 20d):
  - Biogas production 12d (**81%**) & 16d (95%) of 20d. Similar VSR%.
  - Healthy AD process

Remarks

- Laboratory-scale anaerobic sludge digestion (~8L) may imitate field digestion in near-ideal condition

- It allows side-by-side comparison of one independent variable, without other confounding factors

- Thank you