Reduction of Sludge Production

- Alternative to Energy Recovery from Waste Sludge

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Sep. 26, 2017

Introduction

THE PROBLEM

- Waste activated sludge (WAS) generation in Korea (KMOE, 2014) :
  - 3.5 Mil ton/year in 2013
  - steadily increase for the past 10 years with annual average of 4.66%

- Prevention of ocean dumping by London Treaty

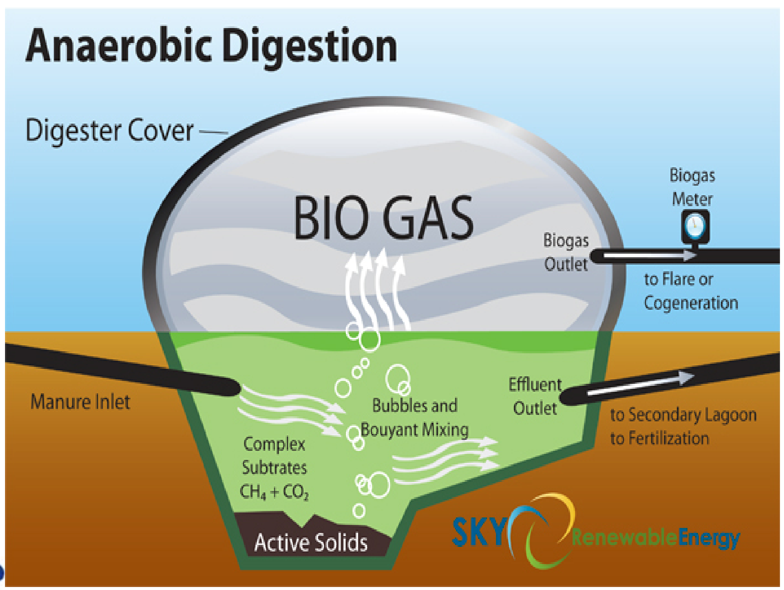
⇒ require appropriate alternatives

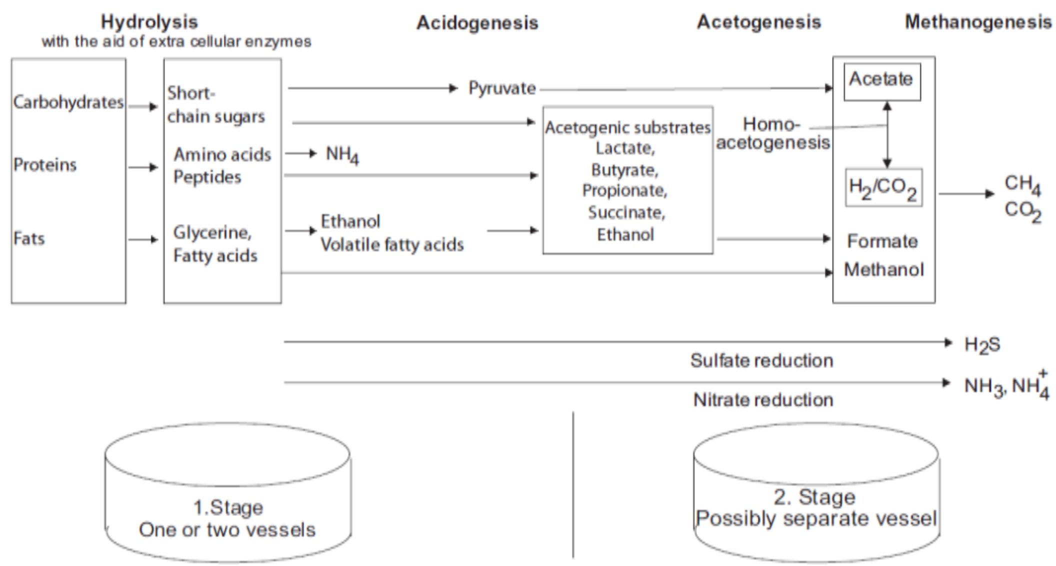
- WAS volume reduction methods :
  - anaerobic digestion
  - pretreatment for enhanced efficiency

⇒ require a relatively high amount of energy consumption

ANAEROBIC DIGESTION

- Methane fermentation : hydrolysis, acidogenesis, acetogenesis, and methanation
- The individual phases : partly stand in syntrophic interrelation and place different requirements on the environment
- Two stages: the first 2 phases and the last 2 phases are linked closely with each other





Anaerobic Digestion Reactors

- Low-rate anaerobic reactors
  - Anaerobic pond
  - Septic tank
  - Imhoff tank
  - Standard rate anaerobic digester

Slurry type bioreactor, temperature, mixing, SRT or other environmental conditions are not regulated. Loading : 1-2 kg COD/m^3-day

- High-rate anaerobic reactors
  - Anaerobic contact process
  - Anaerobic filter (AF)
  - Upflow anaerobic sludge blanket (UASB)
  - Fluidized bed reactor
  - Hybrid reactor: UASB/AF
  - Anaerobic sequencing batch reactor (ASBR)

Able to retain very high concentration of active biomass in the reactor. Thus extremely high SRT could be maintained irrespective of HRT. Loading: 5-20 kg COD/m^3-d

BIOGAS COMPOSITION PRODUCED BY AD

- The gas components: specified to the plant and substrate and should be checked regularly on a long-term basis

Component	Content	Effect
CO_2	25–50% by vol.	Lowers the calorific value
		Increases the methane number and the anti-knock properties of engines
		Causes corrosion (low concentrated carbon acid). if the gas is wet
		Damages alkali fuel cells
H_2S	0–0.5% by vol.	Corrosive effect in equipment and piping systems (stress corrosion); many manufacturers of engines therefore set an upper limit of 0.05 by vol.%
		SO_2 emissions after burners or H_2S emissions with imperfect combustion– upper limit 0.1 by vol.%
		Spoils catalysts
NH_3	0–0.05% by vol.	NO_x emissions after burners damage fuel cells
		Increases the anti-knock properties of engines
Water vapor	1–5% by vol.	Causes corrosion of equipment and piping systems
		Condensates damage instruments and plants
		Risk of freezing of piping systems and nozzles
Dust	>5 µm	Blocks nozzles and fuel cells
N_2	0–5% by vol.	Lowers the calorific value
		Increases the anti-knock properties of engines
Siloxanes	0–50 mg Nm^{-3}	Act like an abrasive and damages engines

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Pretreatment Methods

for Enhanced Biogas Production

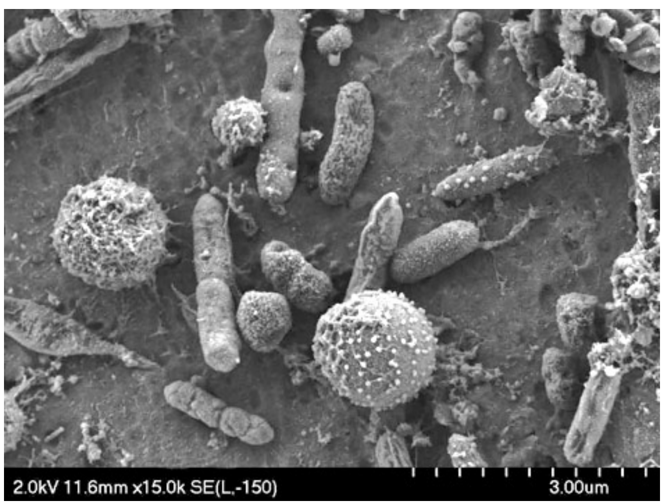
Pretreatment Methods for Enhanced Biogas Production

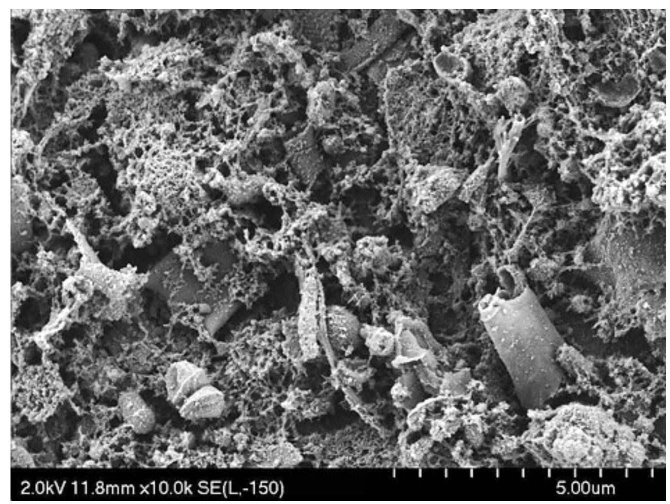
P. L. McCarty at Stanford University

- Looking for a way to improve anaerobic digestion (in the late 1970s)
  - Primary Sludge (PS) : easily digested
  - Waste Activated Sludge (WAS) : only 1/3 can be digested

- Waste Activated Sludge : mostly consisted of microbial cells
  - Protection by cell walls, most cellular material is unavailable to anaerobic microbes.

- Pretreatment Methods : focused on ‘Cell Lysis”
  - Volatile solids reduction (VSR) can be increased 2~3 times.
  - Biogas production can be doubled.





Methods of Cell Lysis

- High temperature (Hydrolysis)
  - Cambi™ by Cambi AS, Norway : 165°C at 6 bar for 20~30 min
  - Exelys™ by Veolia, France : 165°C at 9 bar for 30 min

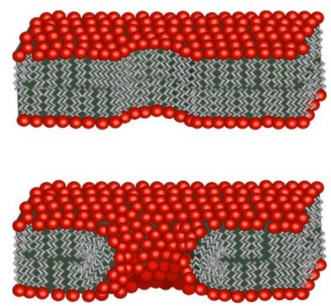
- High Pressure
  - MicroSludge® by Paradigm Environment, Canada : homogenizer (60 bar)

- Physical Force
  - OpenCel® by OpenCel LLC, Atlanta : focused pulse
  - Ultrasound homogenizer

- Others : high or low pH, chemical oxidation, etc.

Cambi™

MicroSludge® Homogenizer



OpenCel® (pores on cell well)

Carbon source production from sludge using Cell Lysis

- Methanol alternatives as C source for denitrification
  - Reduced sludge production & reduced
  - Utilization as C source has 10 times its value making biogas
    - ⇒ Reduced greenhouse gas emission
    - ⇒ Reduced O&M cost

Major Issues on Pretreatment of Sludge

- Cost can be higher than the benefit it can provide !!
  - Benefit (increased biogas production) should be greater than CAPEX + OPEX.
  - There are various unforeseeable and hidden costs.

Reduction

of Sludge Production

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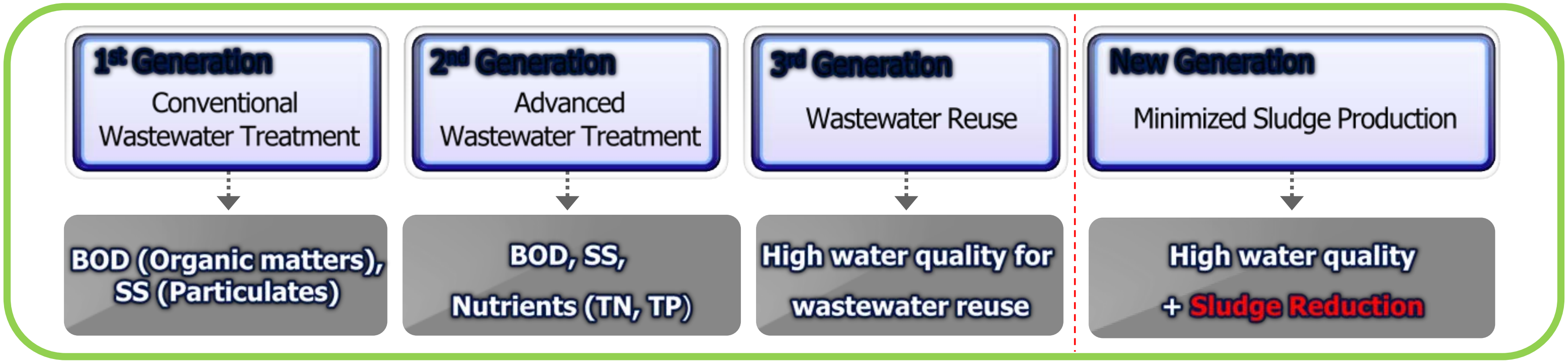
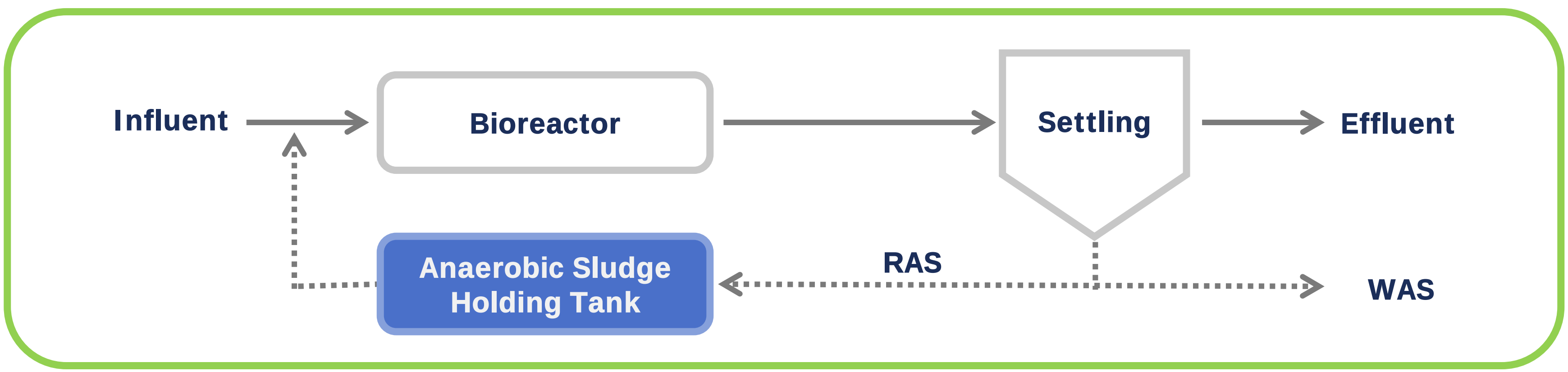
Reduction of Sludge Production

Paradigm Shift

- New technology for source reduction during wastewater treatment by manipulating microbial growth kinetics



- Process Diagram



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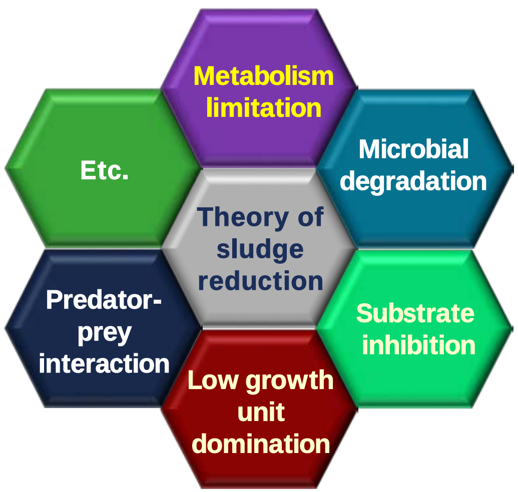
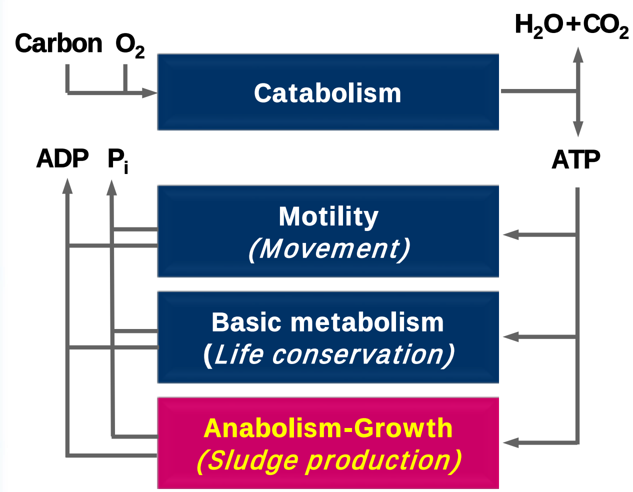
PRINCIPLE OF SLUDGE REDUCTION

- The abrupt change in growth environments
  - "Uncoupling metabolism" most widely studied
  - Yield reduction while maintaining substrate uptake rate
  - The reduction of ATP production in microbial cells

Possible Explanation



Uncoupling Metabolism



Determination of Optimal HRT of the Anaerobic SHT

- Monitoring NH_3-N concentration while incubating anaerobically

  - in the same growth condition of SHT
  - no substrate addition during incubation

- Abrupt increase in NH_3 release rate

  - considered as the start of endogenous phase
  - considered as optimal HRT of SHT

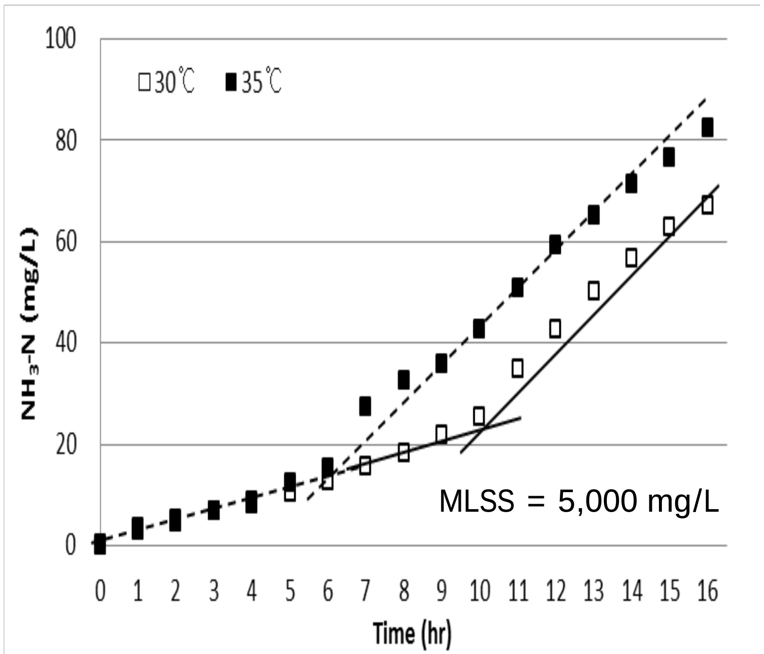
$$\textbf{Biomass N} \rightarrow \textbf{NH}_3\text{-}N + \text{Biomass debris } N$$

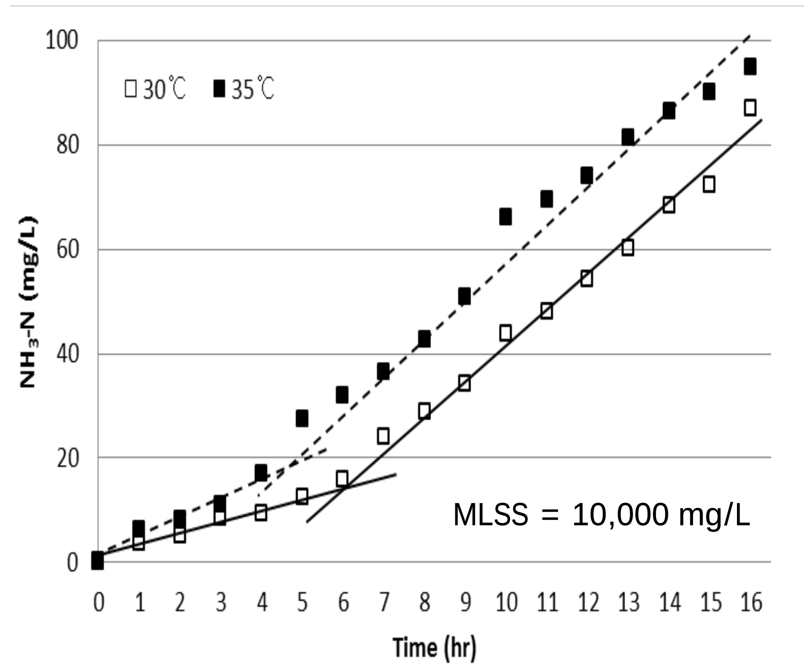
[Conditions for the incubation of sludge]

Incubation Condition	Exp. 1	Exp. 2	Exp. 3	Exp. 4
MLSS (mg/L)	5,000	5,000	10,000	10,000
Temp. (°C)	30	35	30	35

Determination of Optimal HRT of the Anaerobic SHT

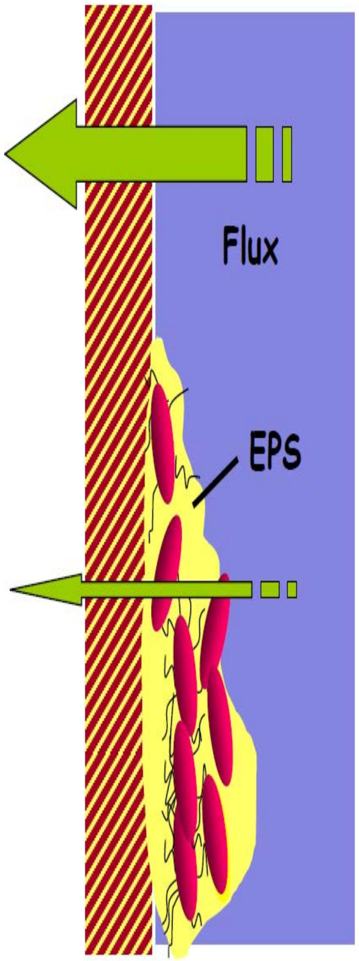
Ammonia Concentration with Time





- **Increase in the release rate = the increased degradation of microbial cells**
- **Optimal point : the start of full endogenous phase at each experimental as the optimal hydraulic retention time for SHT.**

Membrane fouling by EPS



Extracellular polymeric substances (EPS) ?

- EPS are metabolic products accumulating on the bacterial cell surface

Importance…

- EPS is the main cause of membrane fouling
- Reduce water permeability and increase operation cost

Composed of…

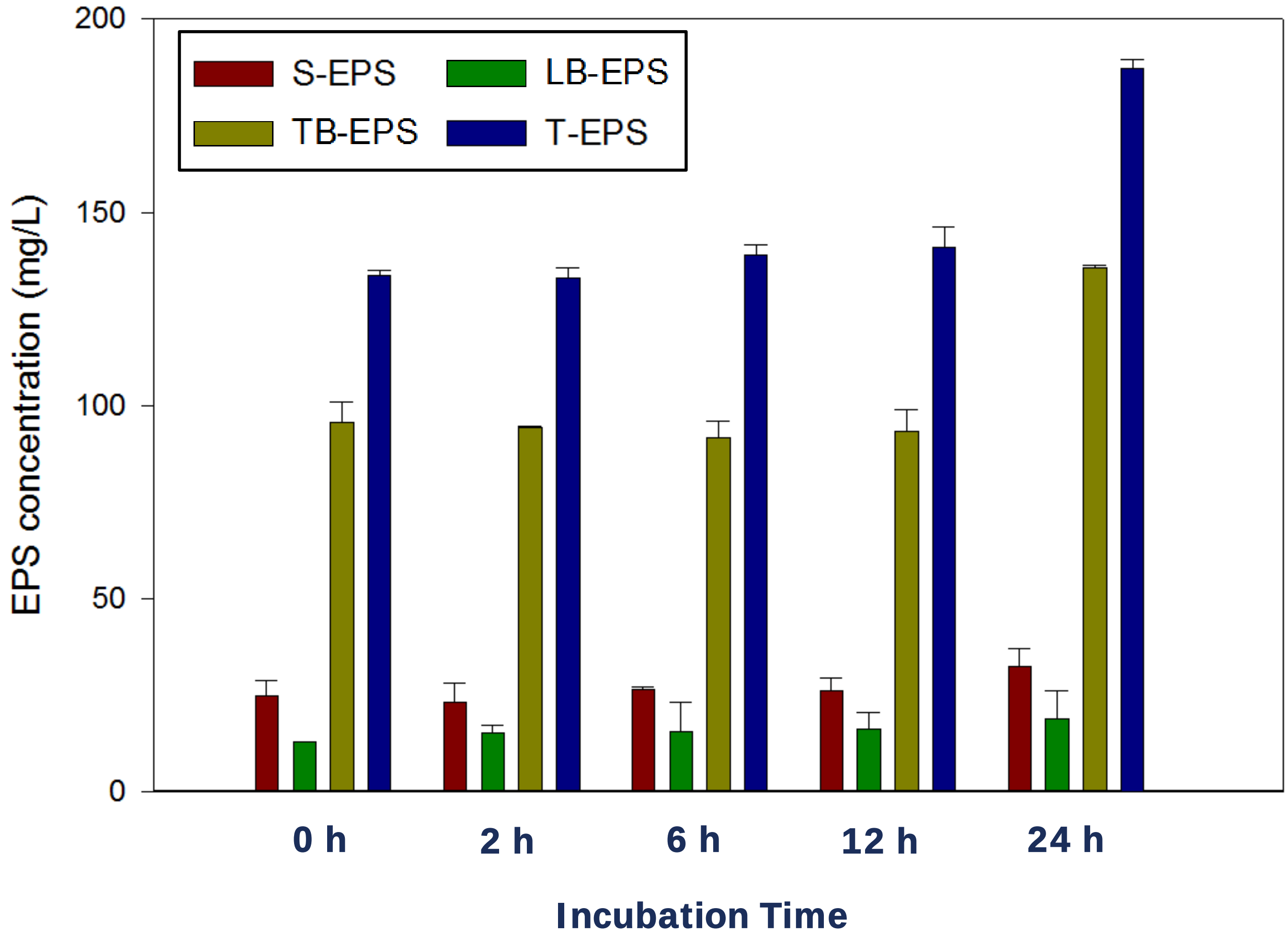
- polysaccharide, protein, humic substances, DNA etc.

Divided into…

- Bound EPS
- Soluble EPS

Determination of Optimal HRT of the Anaerobic SHT

EPS concentrations with respect to anaerobic incubation time



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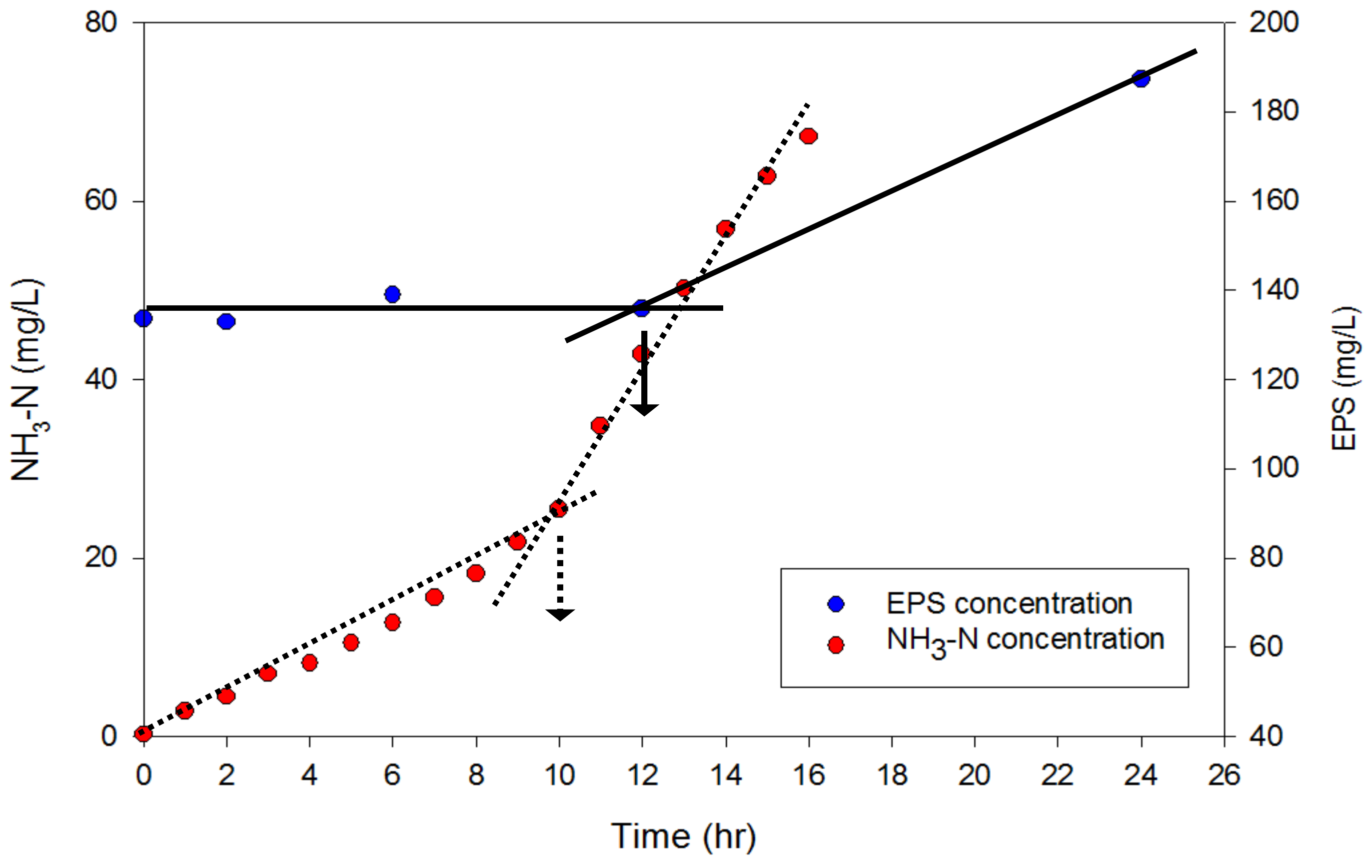
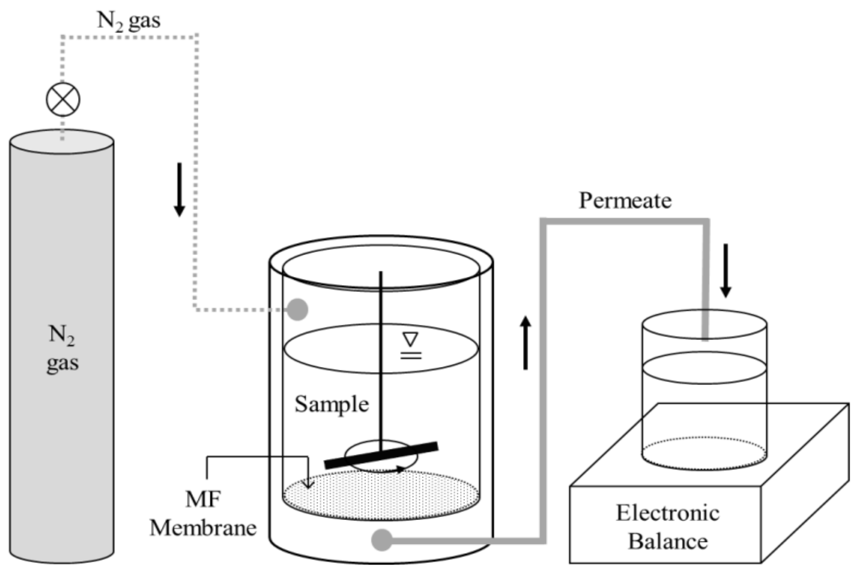
Determination of Optimal HRT of the Anaerobic SHT

Comparison between EPS and ammonia release with incubation time



Determination of Optimal HRT of the Anaerobic SHT

Filterability test



Experimental Conditions

- **Flat sheet PVDF membrane**
- **Pore size: 0.1 ㎛**
- **Membrane area: 32 cm^2**
- **Filtration**
  - **- Pressure : 0.5 bar**
  - **- Volume : 150 ml·MLSS**
- **Backwashing**
  - **- Pressure : 0.5 bar**
  - **- Volume : 150 ml·DI water**

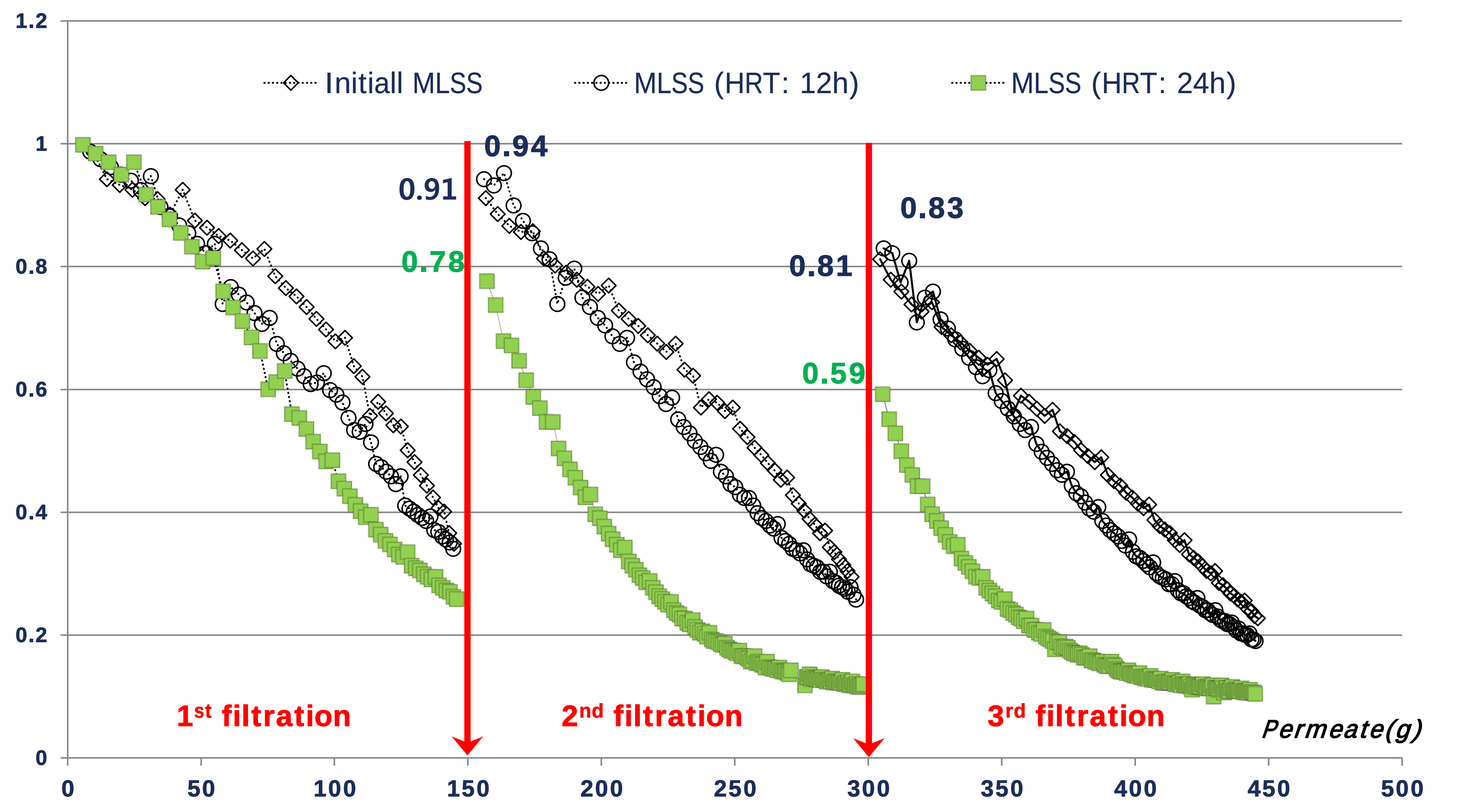
Reversibility of the membranes by backwashing after filtrations

$$IF_n = \frac{J_{p(n-1)} - J_{p(n)}}{J_{P(0)}} \qquad RF_n = \frac{J_{s(n+1)} - J_{e(n)}}{J_{P(0)}} \qquad TF_n = IF_n + RF_n$$

- *IF*, *RF* and *TF* : irreversible, reversible and total fouling, respectively.
- n : the number of the filtration cycle
- $J_{p(n)}$, $J_{s(n)}$ and $J_{e(n)}$: average flux of DI water after rinse, the starting and ending flux of the sludge sample, respectively.

Determination of Optimal HRT of the Anaerobic SHT

Filtration curves of the sludge samples



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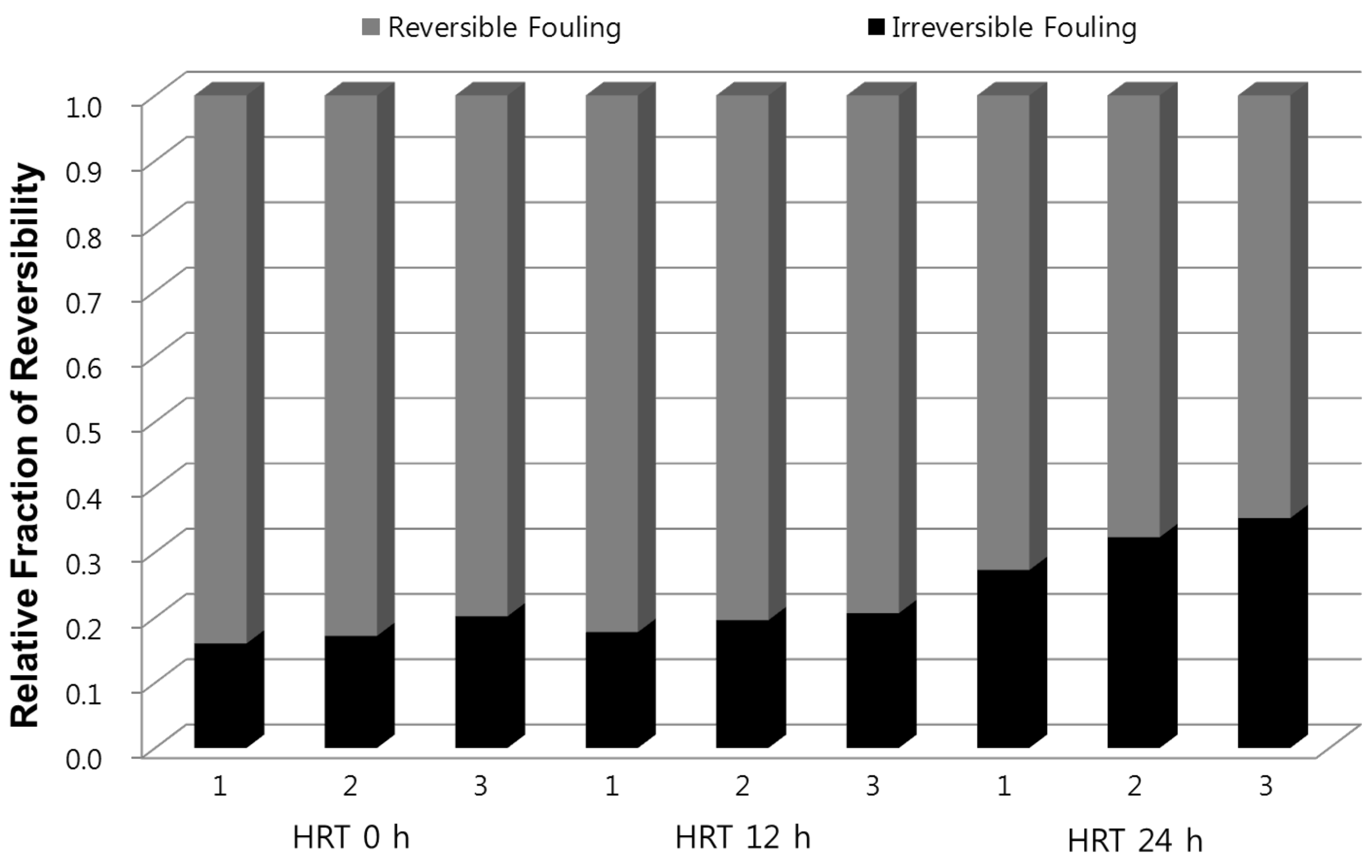
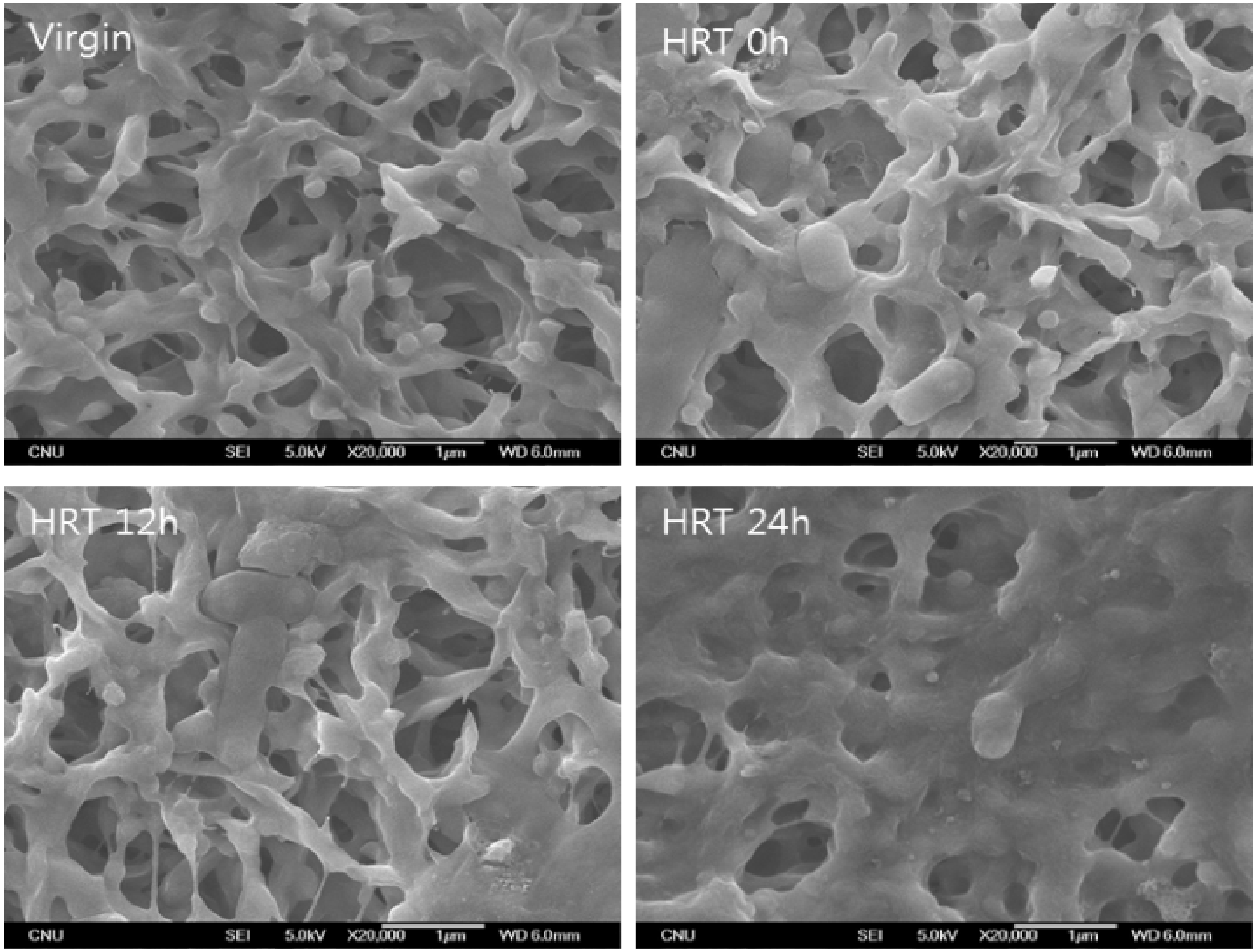
Determination of Optimal HRT of the Anaerobic SHT

Relative fraction of fouling reversibility



Determination of Optimal HRT of the Anaerobic SHT

SEM images of the membranes after 3 times filtration of the mixed liquor



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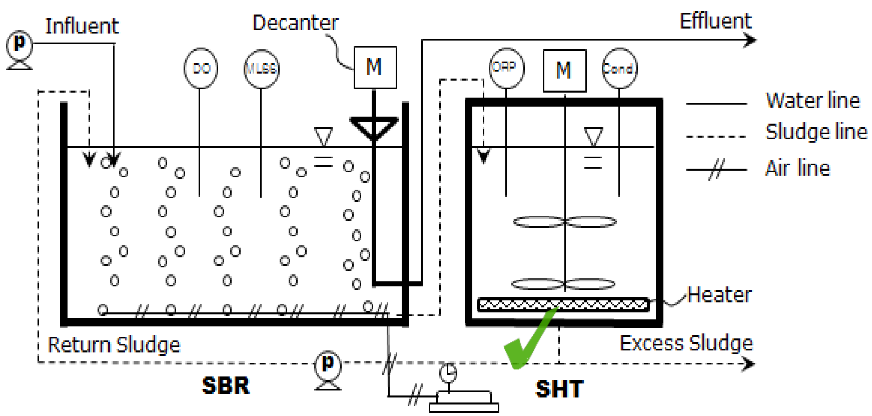
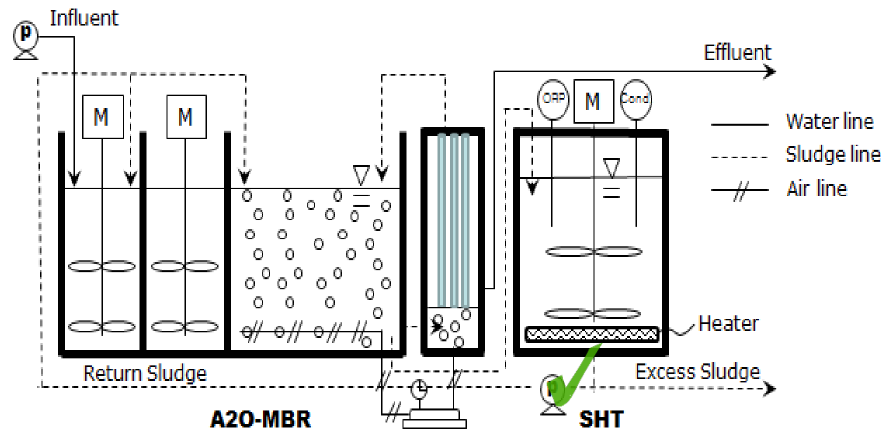
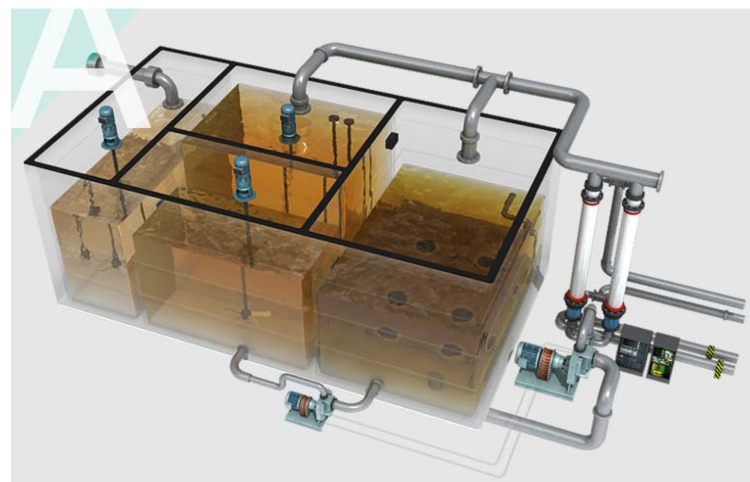
Pilot Operation – SBR and MBR

SBR system with SHT



MBR system with SHT





Kinetic Parameter Estimation

Biological kinetic parameters

⇒ direct evidence of sludge yield reduction

Kinetic parameter estimation :

- SHT was operated in 4 different conditions (as in the experiments of HRT evaluation of SHT, Table 2)
- F/M ratio of 0.15
- For Y_H estimation

$$Y_H = \frac{\Delta Biomass\ COD}{\Delta Soluble\ COD}$$

- For b_H estimation (non-active biomass fraction, f'_p as 0.08)

$$b_H = \frac{b'_H}{1-Y_H(1-f'_p)}$$

- For Sludge production, $P_{X,VSS}$

$$Y_{obs} = \frac{Y_H}{1 + b_H\ SRT}$$

$$P_{X,VSS} = Y_{obs}(Q)(S_0 - S)$$

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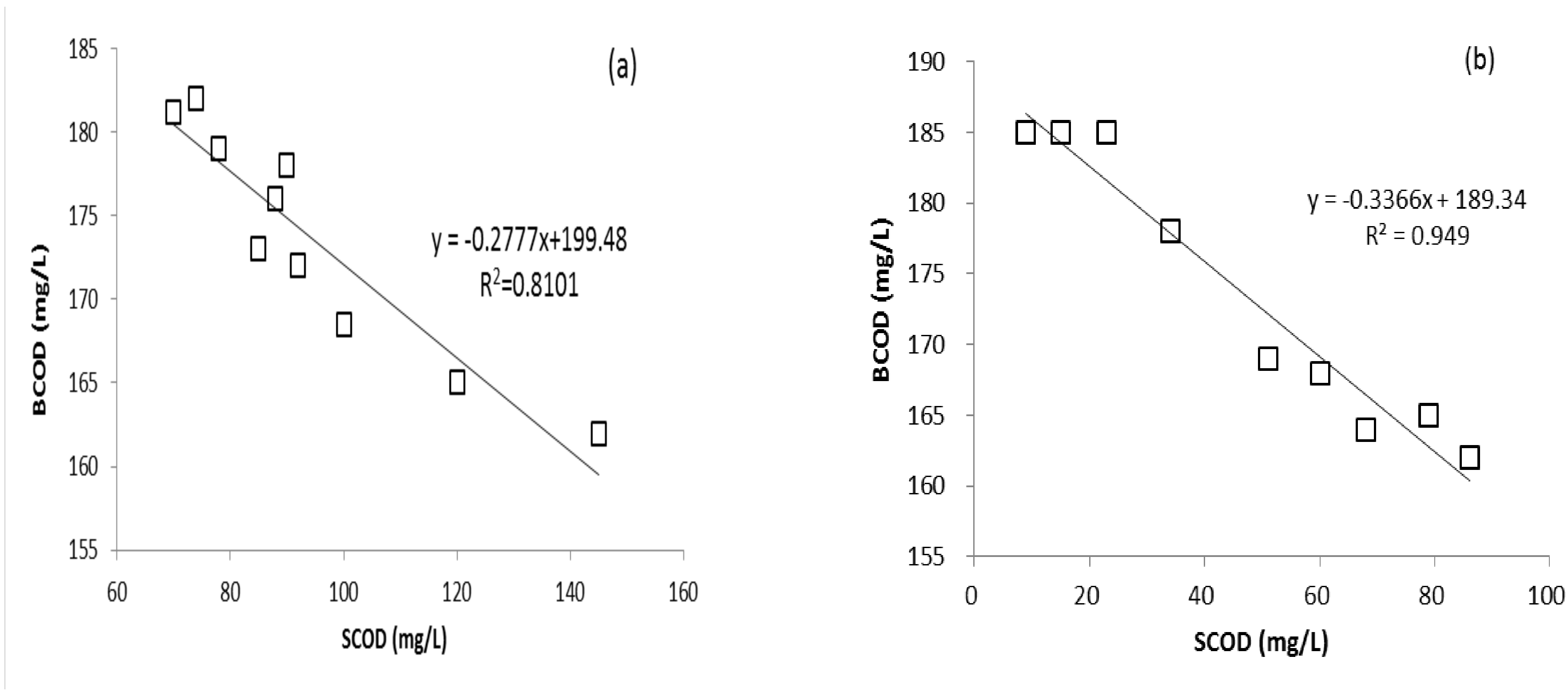
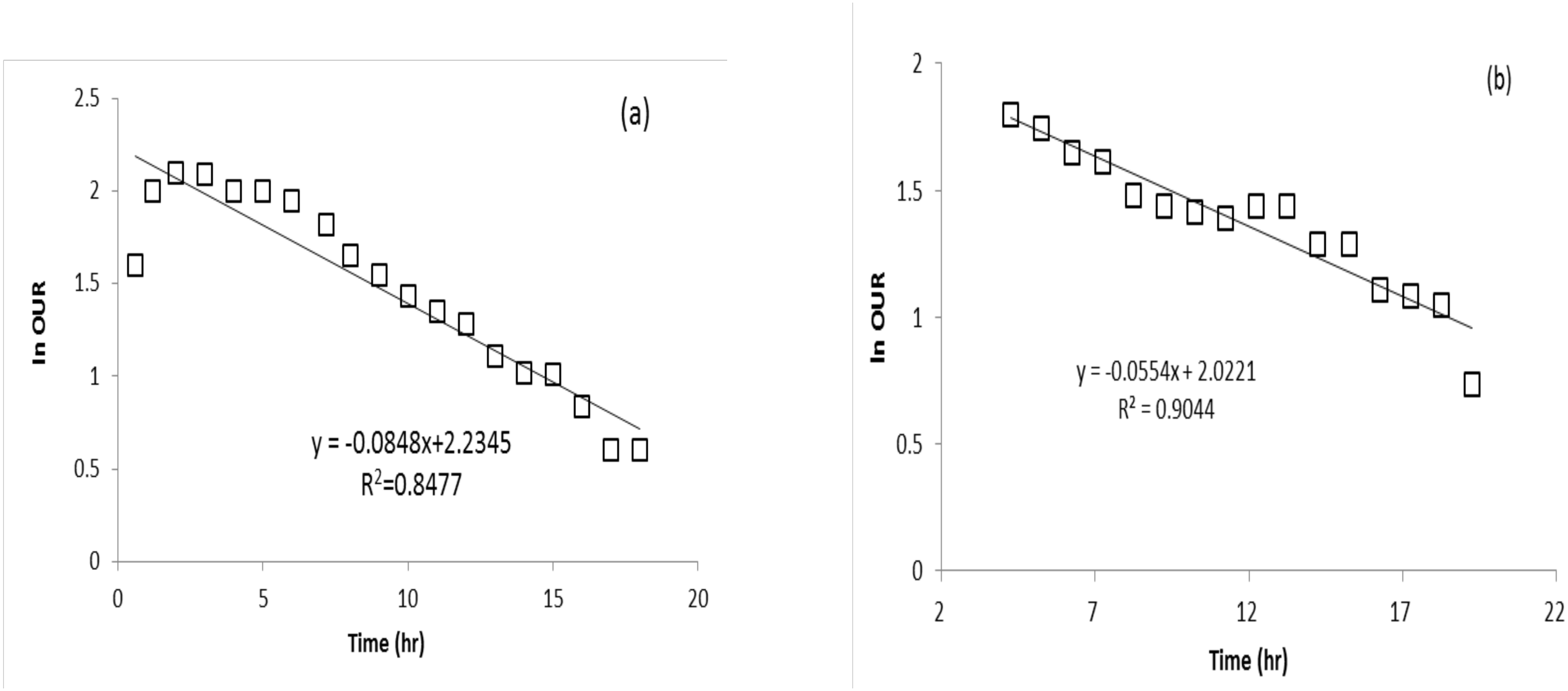
Kinetic Parameter Estimation

Experimental results obtained for Y_H estimation for (a) SBR and (b) MBR systems



Kinetic Parameter Estimation

Experimental results obtained for b_H estimation for (a) SBR and (b) MBR systems



Kinetic Parameter Estimation

Kinetic parameters estimated for the SBR and MBR systems operated with SHT

Conditions		SBR	MBR
SHT	MLSS (mg/L)	5,000	8,000
	Temp. (°C)	30±1	
SRT(day)		68.4	149.6
Y_H		0.28	0.34
b_H (d^{-1})		0.11	0.080
Y_{obs}		0.032	0.026

Reference	Condition		Y_{obs}	Units
Ozdemir and Yenigu (2013)	SRT (day)	10	0.310	kg MLVSS/ kg COD removed
		37	0.220	
		53	0.206	
		110	0.130	
Rensink and Rulkens (1997)	Conventional activated Sludge (23°C)		0.15 – 0.17	kg SS/ kg COD removed
Zhang (2000)	MBR with submerged membrane (suction mode) (20°C)		0.00–0.12	kg SS/ kg COD removed
	MBR with submerged membrane (gravitational mode) (20°C)		0.10–0.15	
Wei et al. (2003)	Conventional activated Sludge (20 °C)		0.17	kg SS/ kg COD removed

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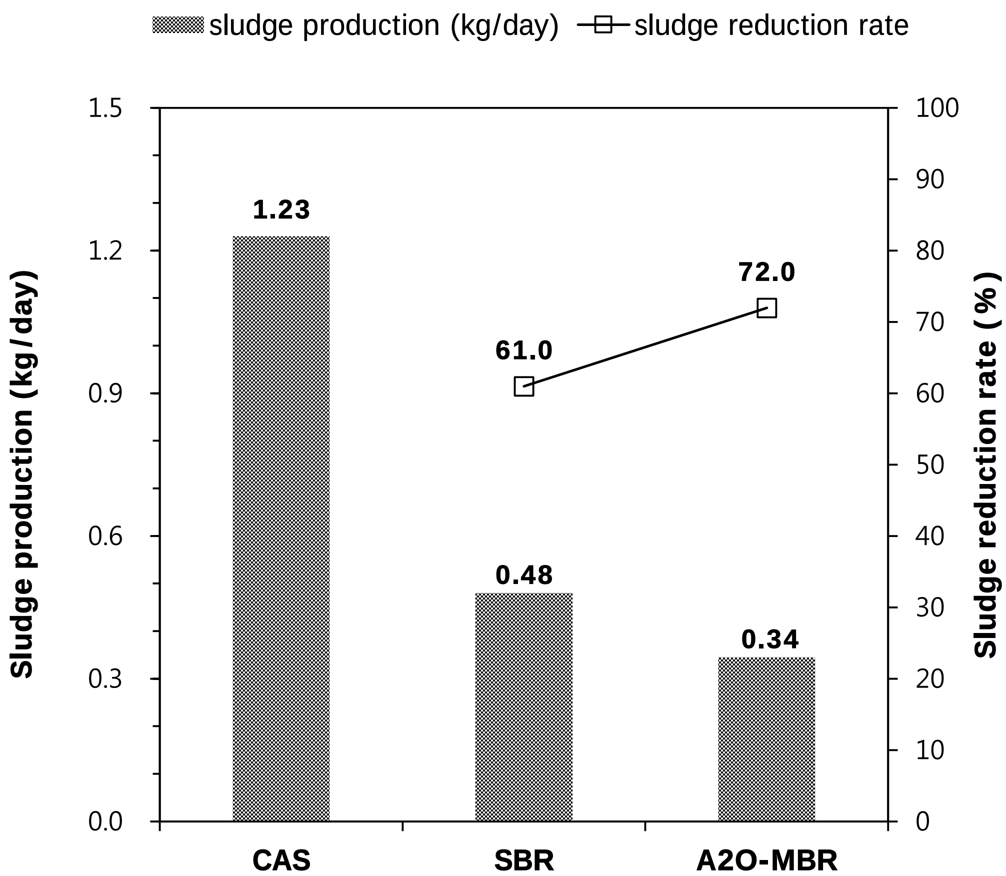
Kinetic Parameter Estimation

Sludge production of MBR and SBR compared to conventional activated sludge (CAS)

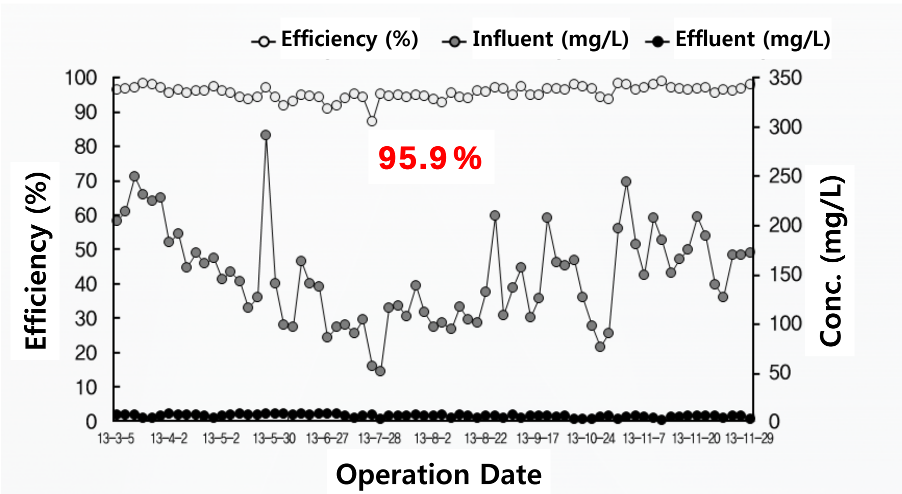


Treatment Efficiency - SBR

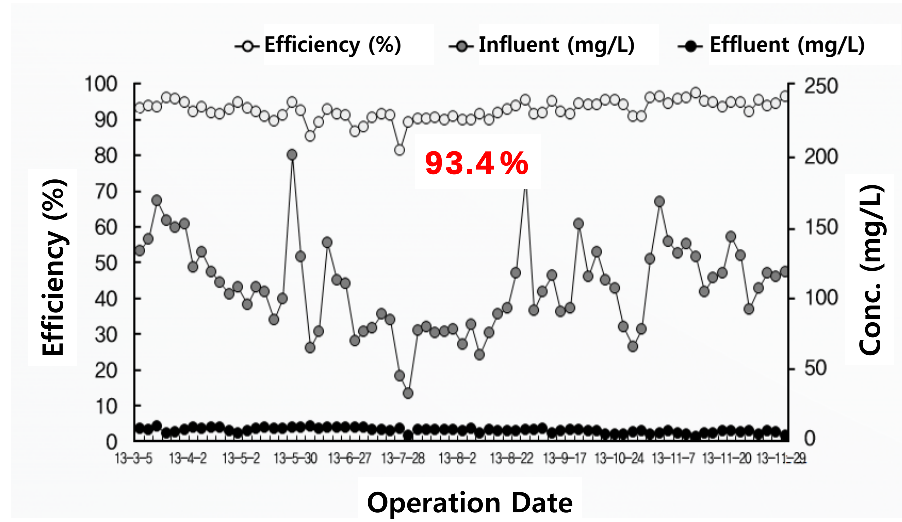
Item	Influent (mg/L)	Effluent (mg/L)	Average efficiency (%)
COD_{Cr}	89.4~310.8	4.6~7.4	95.7
SS	74~191	1.8~6.8	96.1
TN	19.8~41.1	7.8~13.3	65.4
TP	1.7~5.0	0.7~0.9	71.4

Treatment Efficiency - MBR

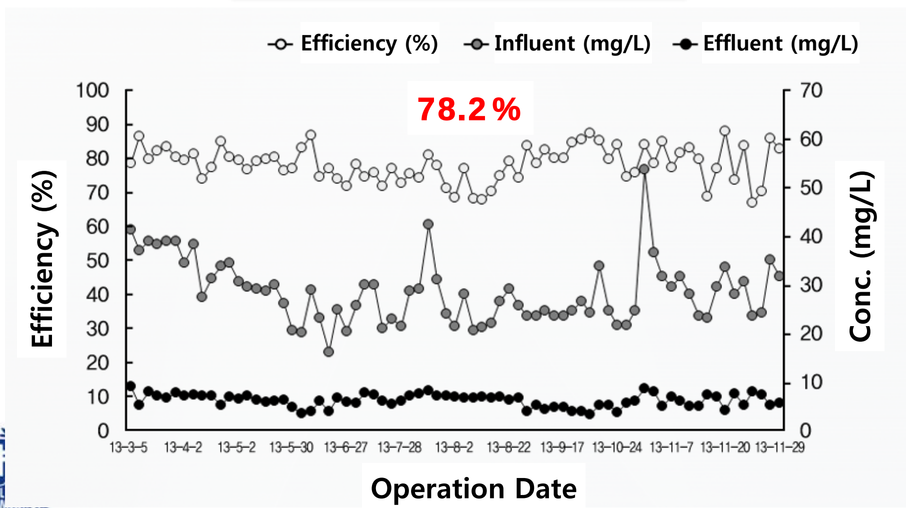
BOD



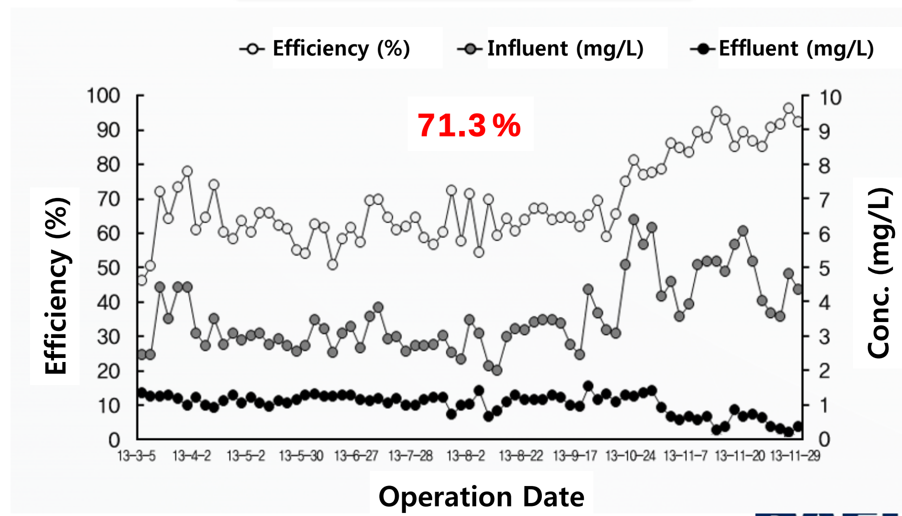
COD



T-N



T-P



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Summary & Conclusion

✓ **Sludge reduction rate by evaluating microbial kinetic parameters**

: Pilot scale SBR and MBR systems operated with anaerobic side-stream SHT, by 61.0% and 72.0%, respectively.

✓ **Treated water quality**

: not deterioration of the effluent water quality but phosphorus removal

✓ **SHT application for various processes with reduced WAS**

: will contribute to minimize environmental and economic problems pertaining to the final disposal of sludge.

✓ **Reduction of sludge production can be**

: an economic and efficient way with net energy gain compared to other pretreatment methods, and

: a sustainable method to reduce sludge disposal cost.

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Thank You !

(Q & A)