NEW APPROACHES TO MINIMIZE EXCESS SLUDGE IN ACTIVATED SLUDGE SYSTEMS

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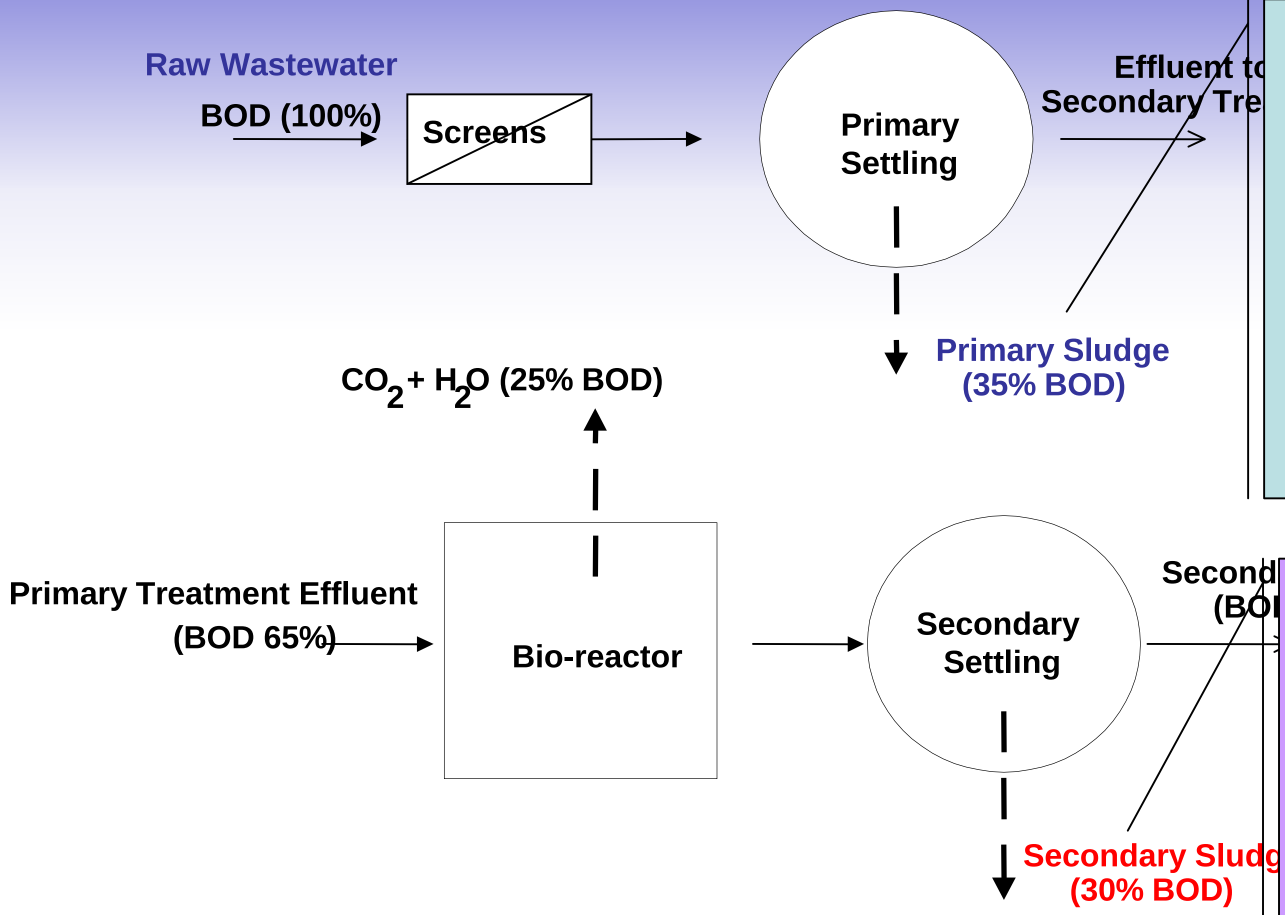
Introduction

Activated **sludge production, treatment and disposal**

Sludge Production



Primary sludge:
110-170 kg dry solids /10^3 m^3 of wastewater treated

3 $m^3/10^3 m^3$ wastewater treated

Secondary sludge:
70-100 kg dry solids /10^3 m^3 of wastewater treated

8 $m^3/10^3 m^3$ wastewater treated

$$\text{organic matter} + O_2 + \text{nutrients} \xrightarrow{\text{microorganisms}} CO_2 + H_2O + \text{new cells}$$

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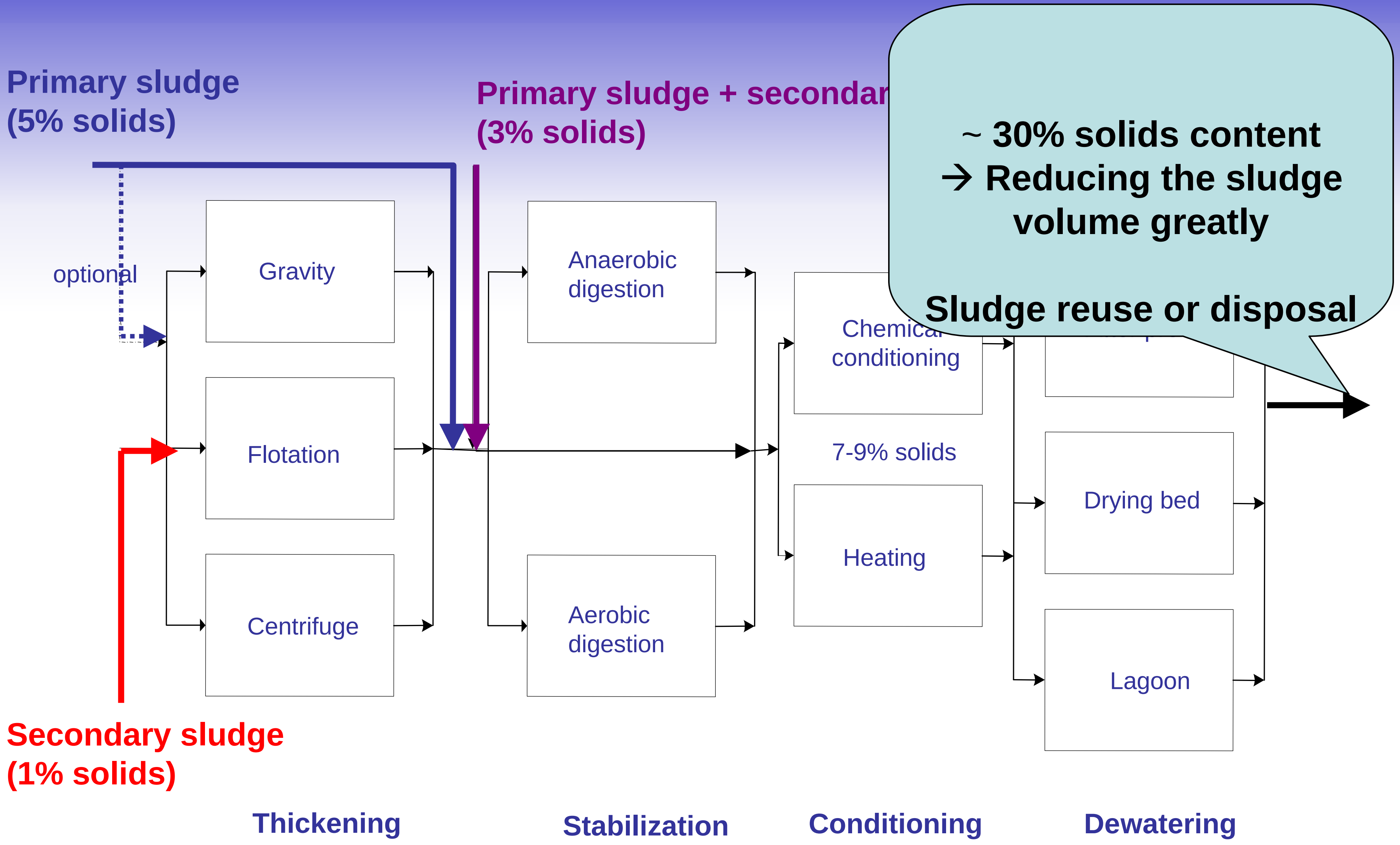
Sludge Treatment



Primary sludge
(5% solids)

Primary sludge + secondar
(3% solids)

~ 30% solids content
→ Reducing the sludge volume greatly

Sludge reuse or disposal

optional

Gravity

Flotation

Centrifuge

Anaerobic digestion

Aerobic digestion

Chemica
conditioning

7-9% solids

Heating

Drying bed

Lagoon

Secondary sludge
(1% solids)

Thickening

Stabilization

Conditioning

Dewatering

Sludge Disposal

Landfill

- The most preferred means
- Capacity is limited
- Lack of new location

Incineration

- Practiced in large municipalities
- Air pollution

Land application

Reuse of sludge nutrient
Soil amendment
Sludge should be less contaminated

Ocean dumping

Water pollution control regulations

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Sludge Disposal

Best solution will be reducing excess sludge production during the wastewater treatment, or recovering energy and resources from sludge

Landfil

- The mos
- Capacit
- La

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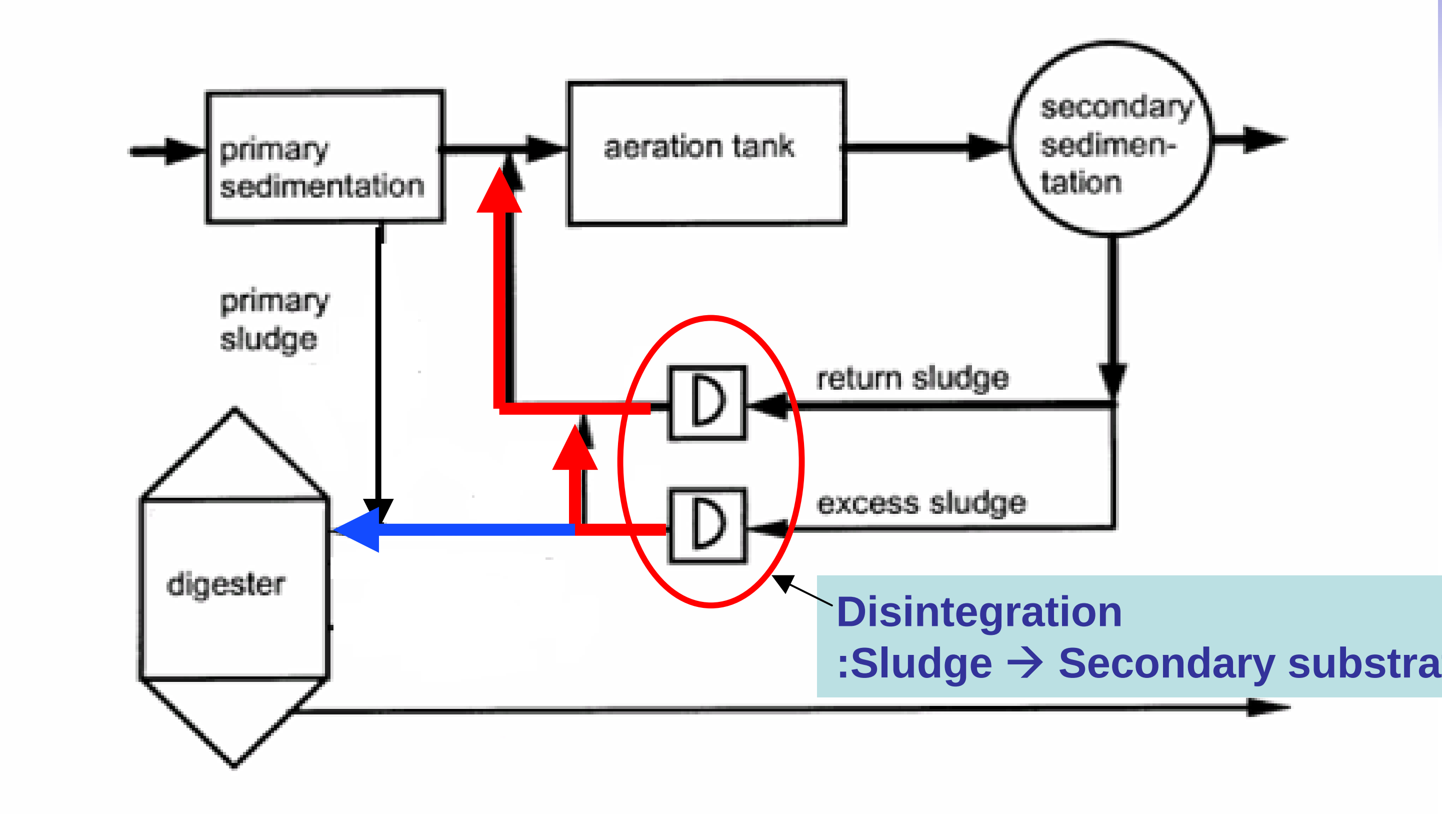
ollution control regulations

Reuse of sludge nut
Soil amendment
Sludge should be less contaminated

Major Approaches of Excess Sludge Reduction

Major Approaches of Excess Sludge Reduction

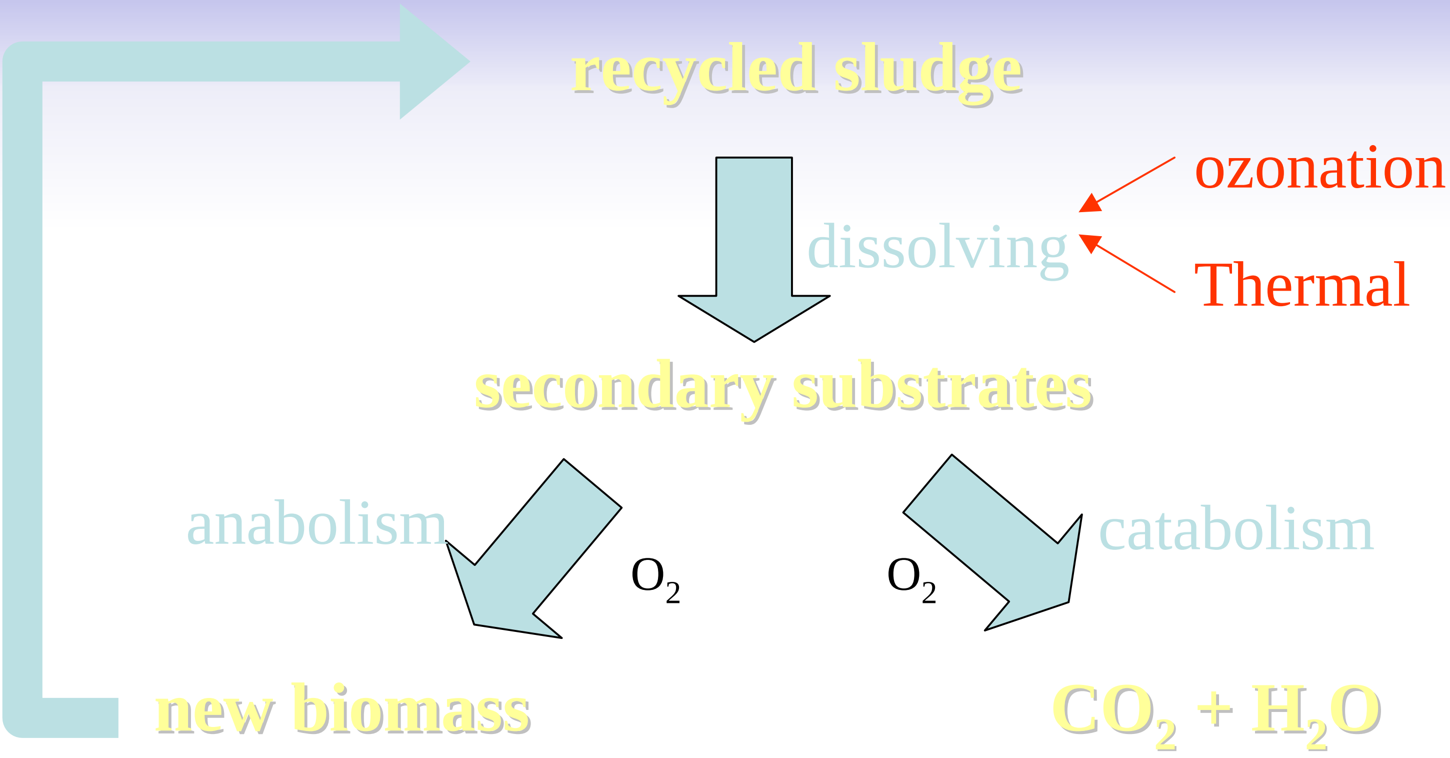


Disintegration
:Sludge → Secondary substrate

(1) Sludge pretreatment through thermal, mechanical, or ozone treatment

(2) Restricting/limiting sludge growth in an aeration tank

Why Sludge Solubilization/disintrgation can Reduce Excess Sludge Production



recycled sludge

dissolving

ozonation

Thermal

secondary substrates

anabolism

catabolism

O_2

O_2

new biomass

$CO_2 + H_2O$

As a result, excess sludge can be reduced

[1] Applied force for sludge pretreatment

- **Heat treatment under a high temperature up to 180ºC**

  [R. T. Haugh *et al*.,1978]

  [J. Pinnekamp ,1989], [U. Kepp *et al*., 2000], [A. Canales *et al*., 1994]

- **Mechanical pretreatment using ultrasonication, mills and homogenizers**

  [G. Lehne, A. Muller and J. Schwedes 2001], [K. Nickel *et al*., 1998]

  [U. Basier and P. Schmidheiny, 1997]

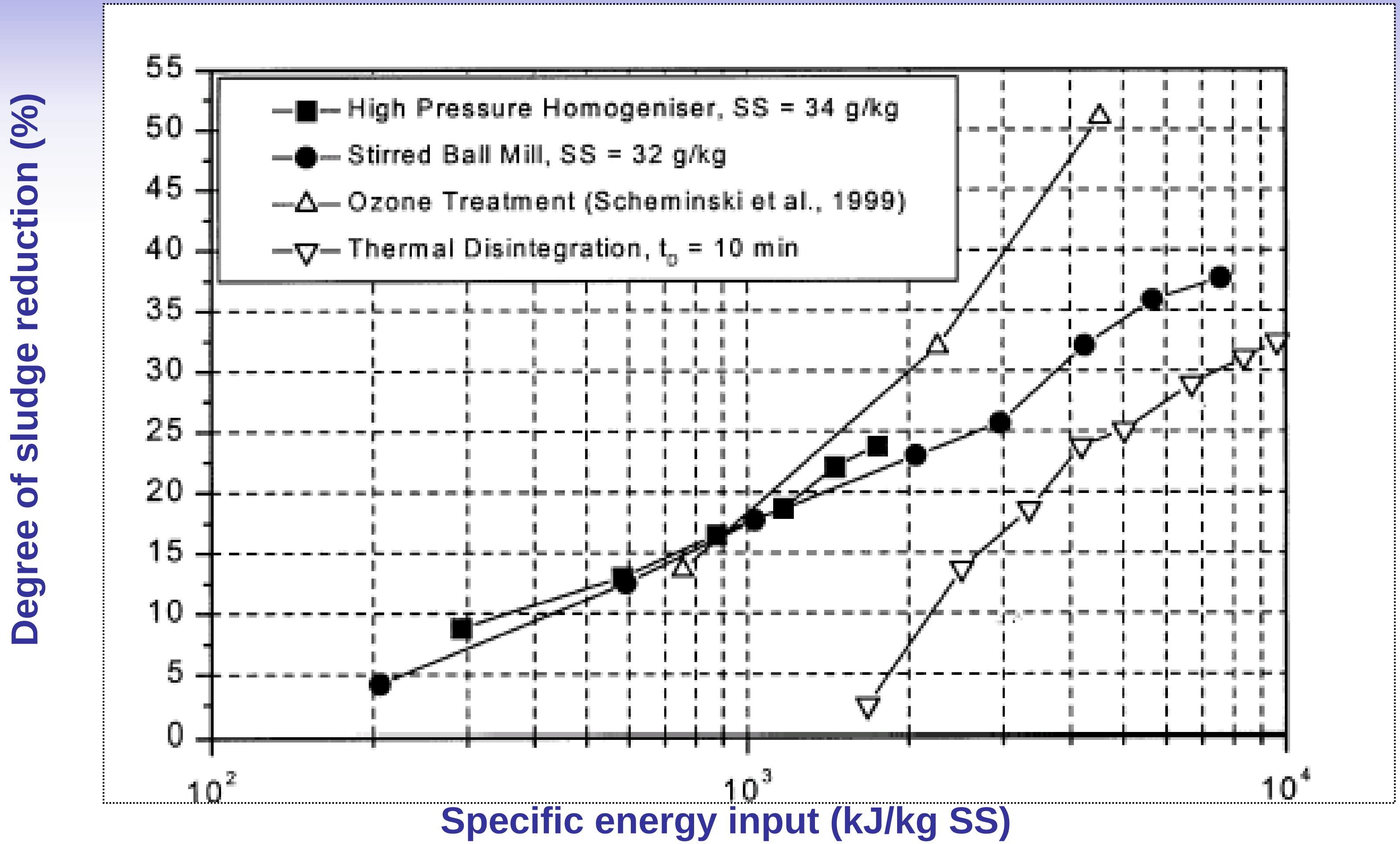
  - Stirred Ball Mills (SBM)
  - High Pressure Homogenizers (HPH)
  - Ultrasonic Homogenizers (UH)
  - Mechanical Jet Smash Technique (MJS)
  - High Performance Pulse Technique (HPP)
  - Lysat-Centrifugal-Technique (LC)

- **Ozonation**

  [H. Yasui and M. Shibata,1994], [E. Egemen *et al*., 2001]

  [T. Kamiya, and J. Hirotsuji, 1998], [M. Weemaes *et al*., 2000]

[1] Specific energy consumption with various pretreatment methods [J. Müller,2000]



[1] Comparison of various sludge pretreatment methods

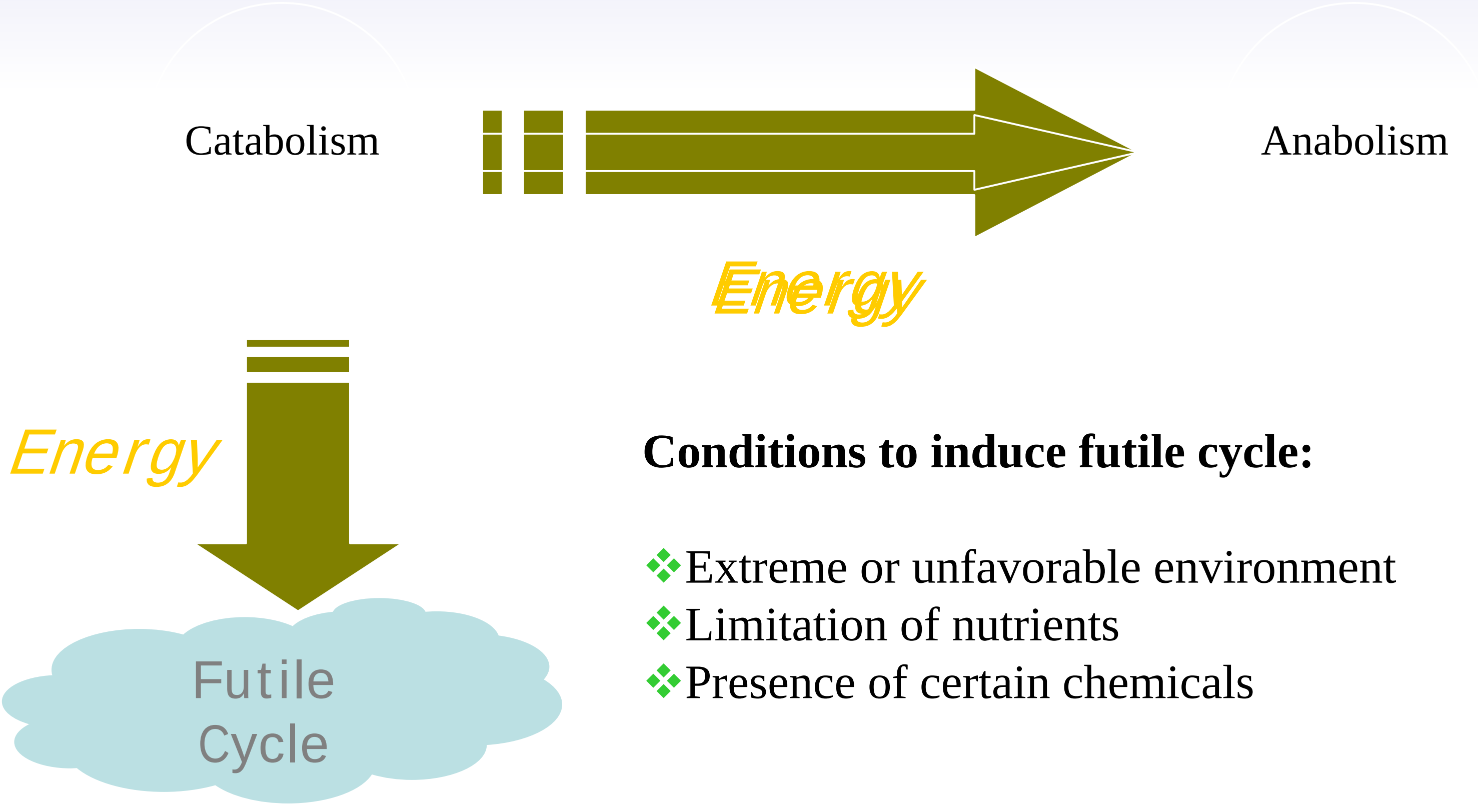
Sludge pretreatment method	Sludge reduction efficiency	Energy requirement	Operational cost	Disadvantages
Thermal	Low	High	High	Produce non-biodegradable organic matter at high temperature Odor generation
Mechanical	High	High	High	High cost Suitability of the machines for practical application is major concern
Ozonation	High	Relatively low	Relatively low	Poor sludge settling Odor generation

[2] Restricting/limiting sludge growth in an aeration tank

A significant reduction in sludge production could be achieved by restricting/limiting sludge growth under the following conditions:

1. at high temperatures [P. Coultate and K. Sundaram,1975], [I. Nioh and C. Furusaka,1968]
2. with the presence of metabolic inhibitory substances [G.H Chen *et al*., 2000];
3. with nutrients limitation [S. P. Tsai, 1990]
4. with the presence of higher forms of microorganisms such as protozoa and metazoa [C. H. Ratsak *et al*., 1994]; [J. H. Rensink *et al*., 1997]
5. with a long SRT as in an extended aeration process and MBR process [S. Chaize and A. Huyard , 1993].

[2] Concept of restricting/limiting sludge growth through futile cycle or energy uncoupling



Conditions to induce futile cycle:

- Extreme or unfavorable environment
- Limitation of nutrients
- Presence of certain chemicals

Sludge Pretreatment vs Sludge Growth Restriction

Sludge Pretreatment	Sludge Growth Restriction
60-100% excess sludge reduction	50-80% excess sludge reduction
High energy input	Lower energy input
Require modification of treatment plant	Little modification of treatment plant

Major Shortcomings of the Present Methods

- **Poor Sludge Settling**
- **Higher Oxygen Requirements**
- **Reduced Nutrient and Substrate Removal**
- **Alternative method for reducing excess sludge production, which is feasible and cost-effective, is necessary**

New Approaches to Reduce Excess Sludge Studied at HKUST

1. Chemically stimulated futile cycle
2. Chlorination pretreatment of sludge
3. Oxic-Settling-Anaerobic (OSA) process
4. Autotrophic denitrification

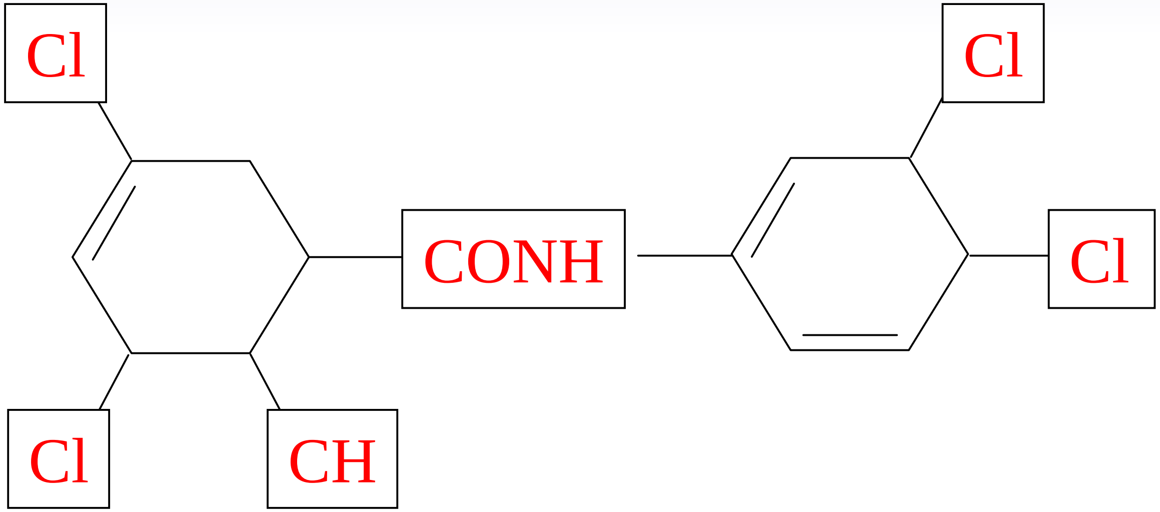
Ideal Chemicals to Stimulate Futile Cycle

- Low cost
- High efficiency
- Low toxicity
- Less impact on substrate removal capacity

3, 3’, 4’, 5-tetrachlorosalicyanide (TCS)

Chemical Structure of TCS

A chemical compound, 3,3’,4’,5-tetrachlorosalicylanilide (TCS) can stimulate futile cycle in *Streptococcus bovis*

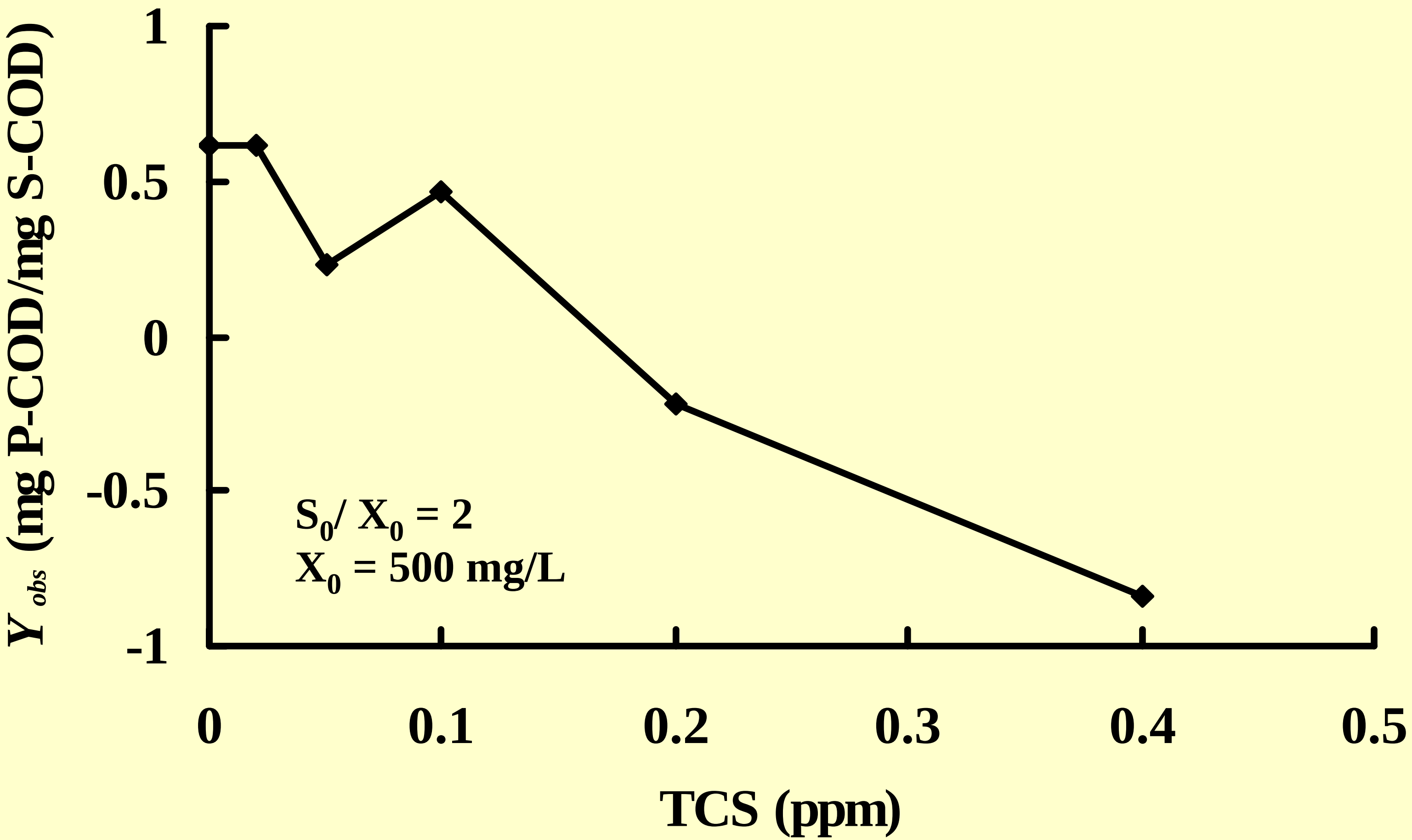


- One of the formulations of soaps, rines, polishes, shampoo, deodorants

Work Scope

- ✓ to investigate the effect of TCS on sludge growth rate and substrate utilization rate
- ✓ to find out an appropriate TCS dosage to induce excess sludge reduction
- ✓ to examine the response of microbial activity to the TCS dosage

- Methodology:
  - pure culture of E.Coli
  - batch and continuous mixed cultures cultivated with and with out TCS
  - endogenous decay coefficient study

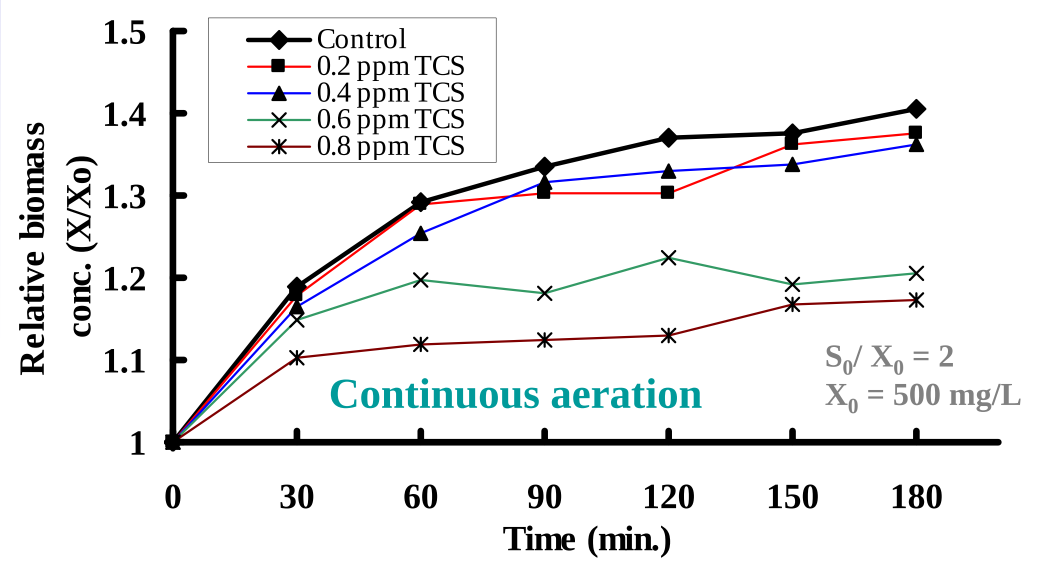


Effect of TCS on the observed growth yield (Y_{obs}) of *E. coli* at different TCS concentration

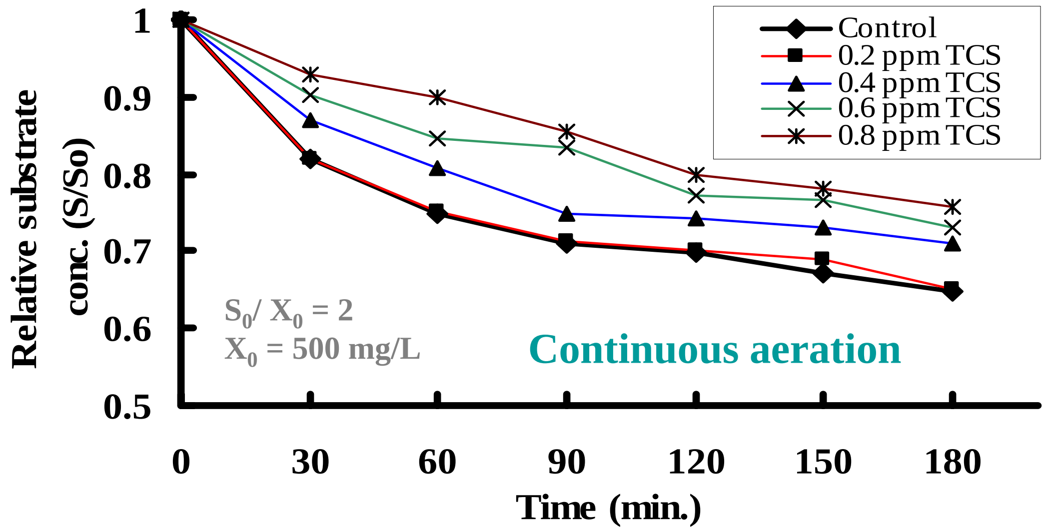
Change of ATP content in *E. coli* at different TCS concentrations

TCS concentration (ppm)	*ΔATP content (μg/mg SS)*
0.0	-1.59
0.02	-1.62
0.05	-1.77
0.1	-1.90
0.2	-1.88
0.4	-2.16

Effect of TCS on Sludge Growth Rate and Substrate Removal Rate

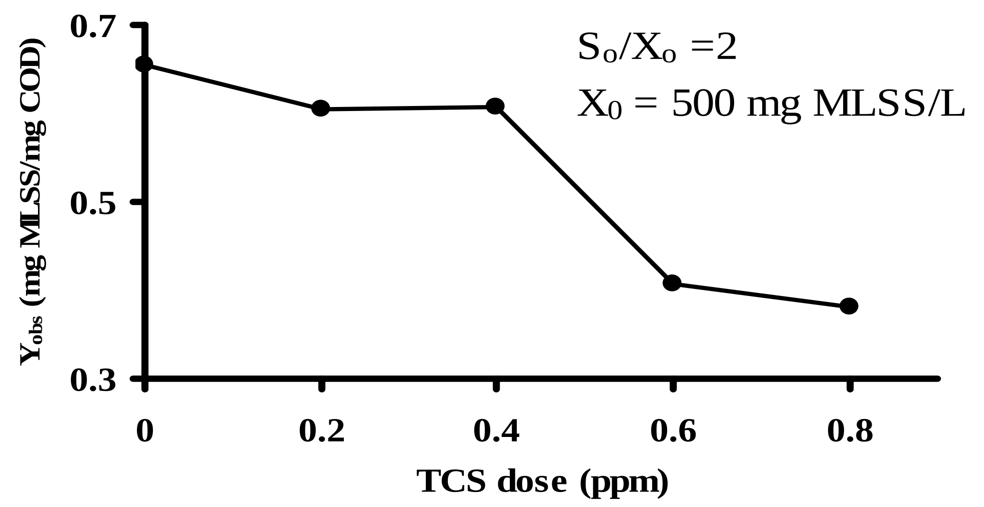


significant effect on sludge growth when TCS > 0.4 ppm



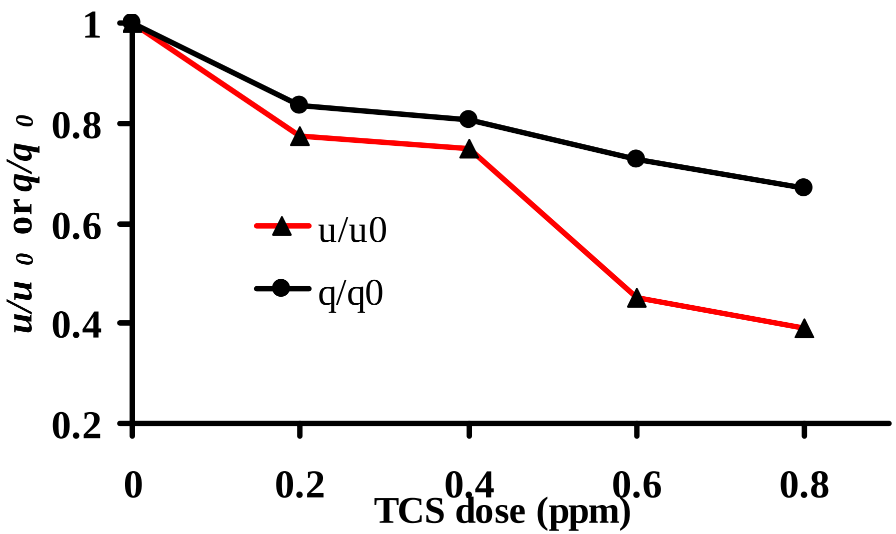
Significant effect on substrate uptake rate when TCS >0.4 ppm

Effect of TCS on Observed Growth Yield



TCS reduces the Y_{obs}

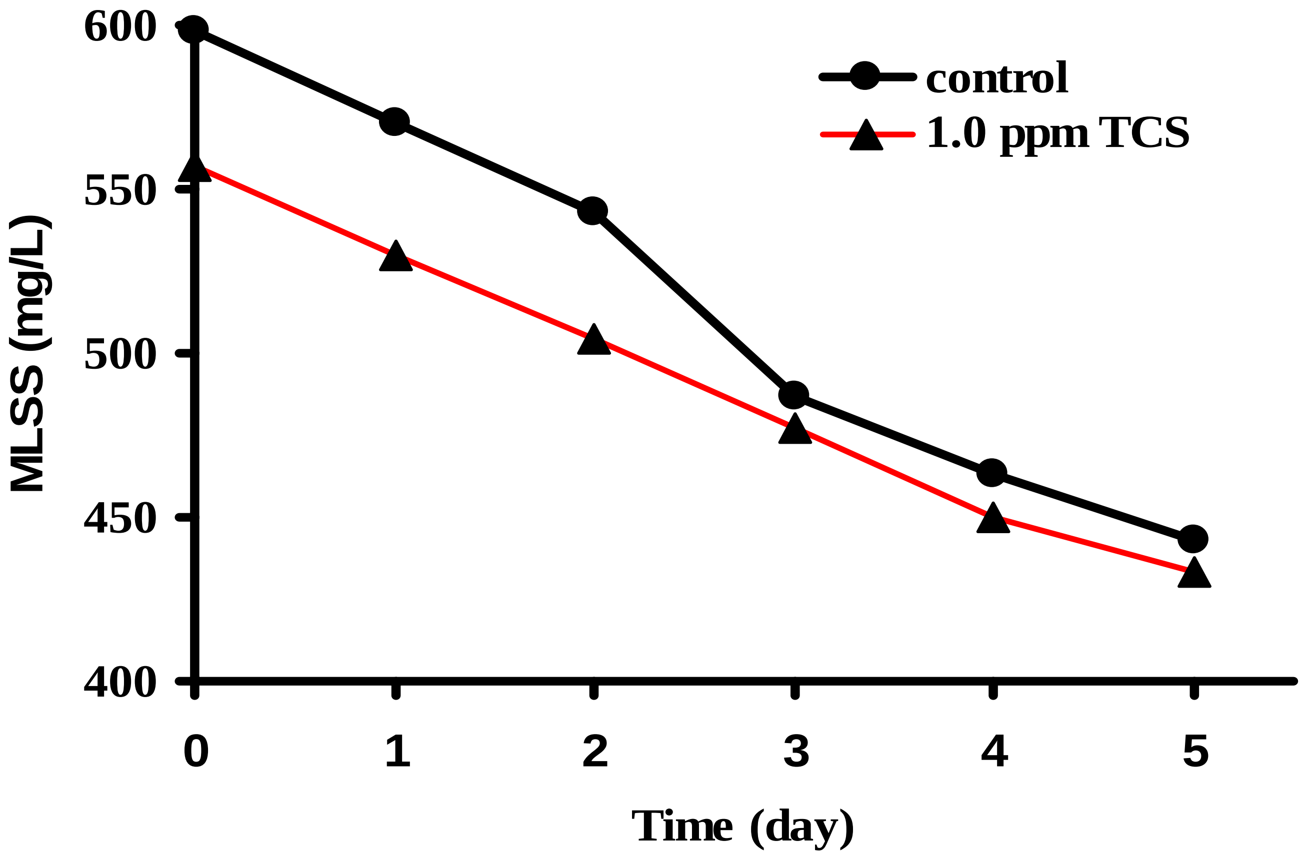
A shape drop of Y_{obs} is detected between 0.4 and 0.6 ppm TCS introduction



TCS reduces both the μ and q

The change of μ resemble that of Y_{obs}

Effect of TCS on Sludge Decay Rate



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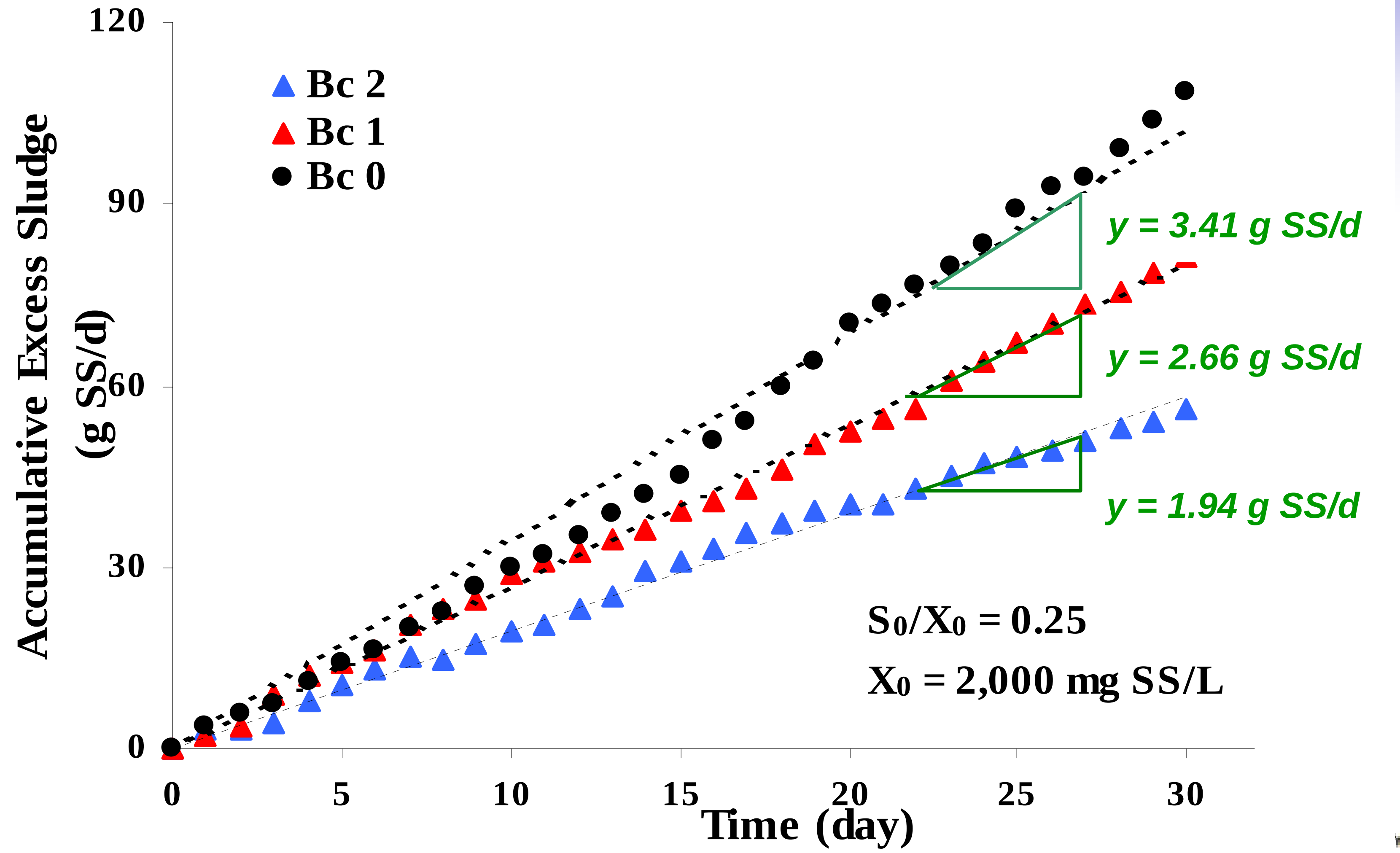
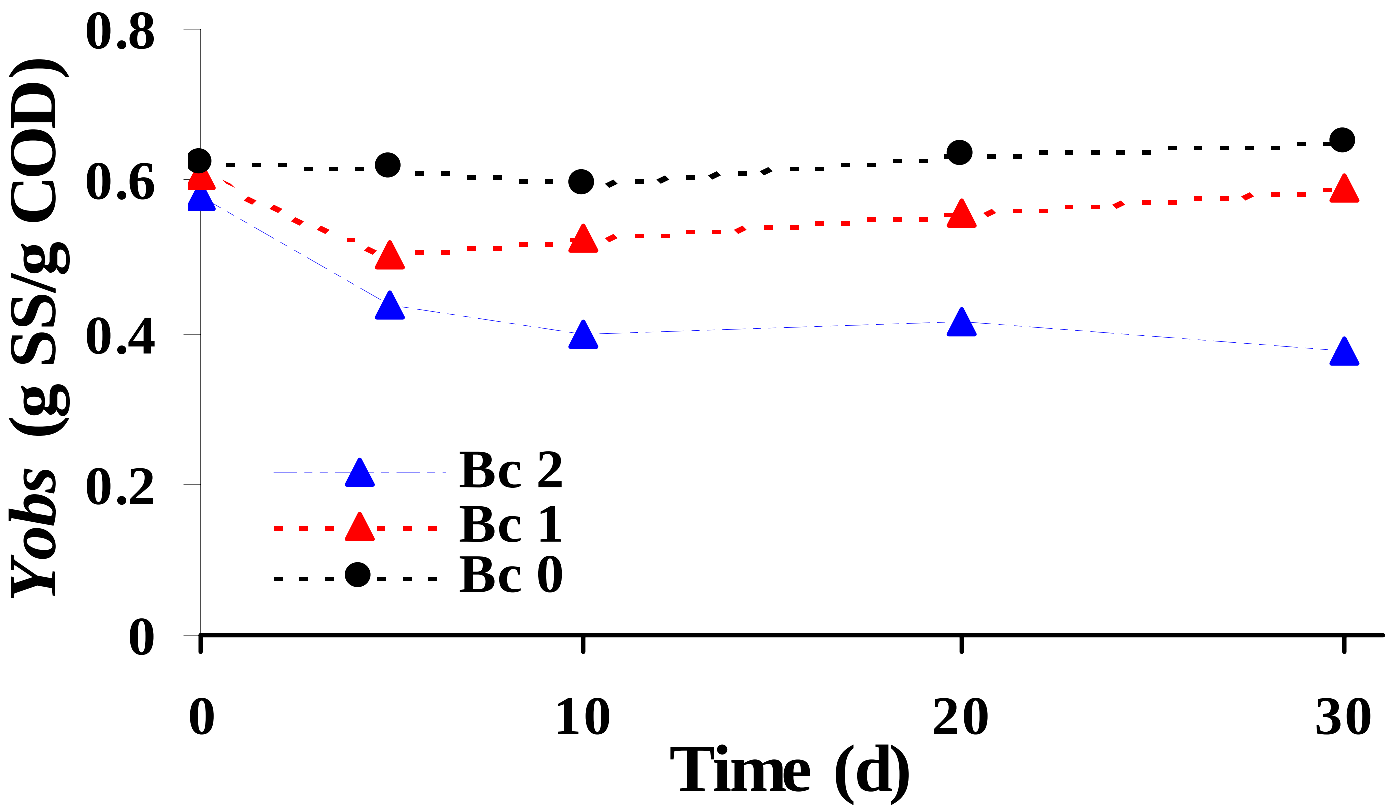
Effect of TCS on Cumulative Excess Sludge Production of Batch Cultures



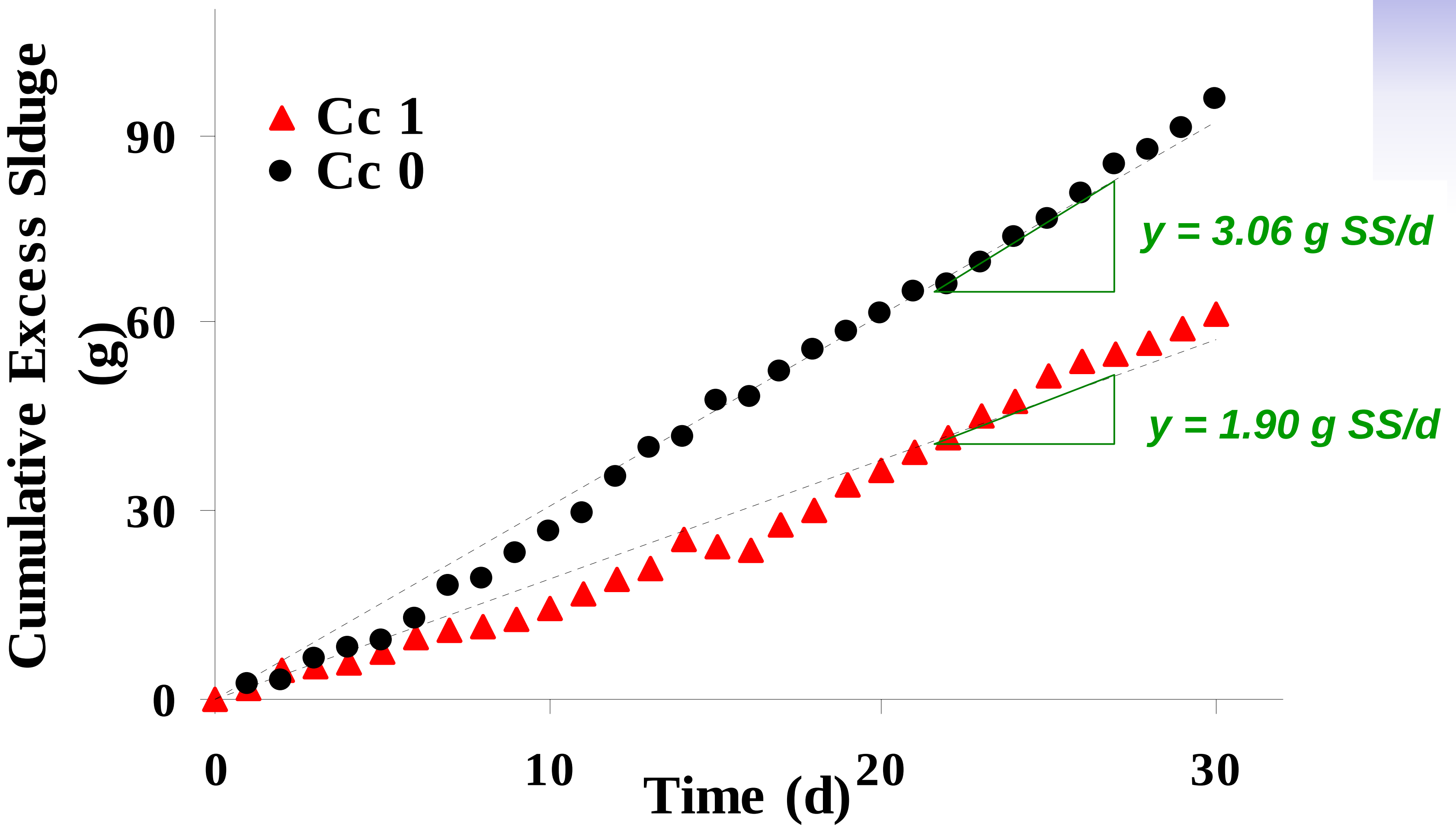
Nomenclatures in the Results and Discussion

Symbol	Description
Bc 0	Batch cultivation without the presence of TCS (control)
Bc 1	Batch cultivation with the presence of 0.5 ppm TCS
Bc 2	Batch cultivation with the presence of 1.0 ppm TCS
Cc 0	Continuous cultivation without the presence of TCS
Cc 1	Continuous cultivation with the presence of 1.0 ppm TCS

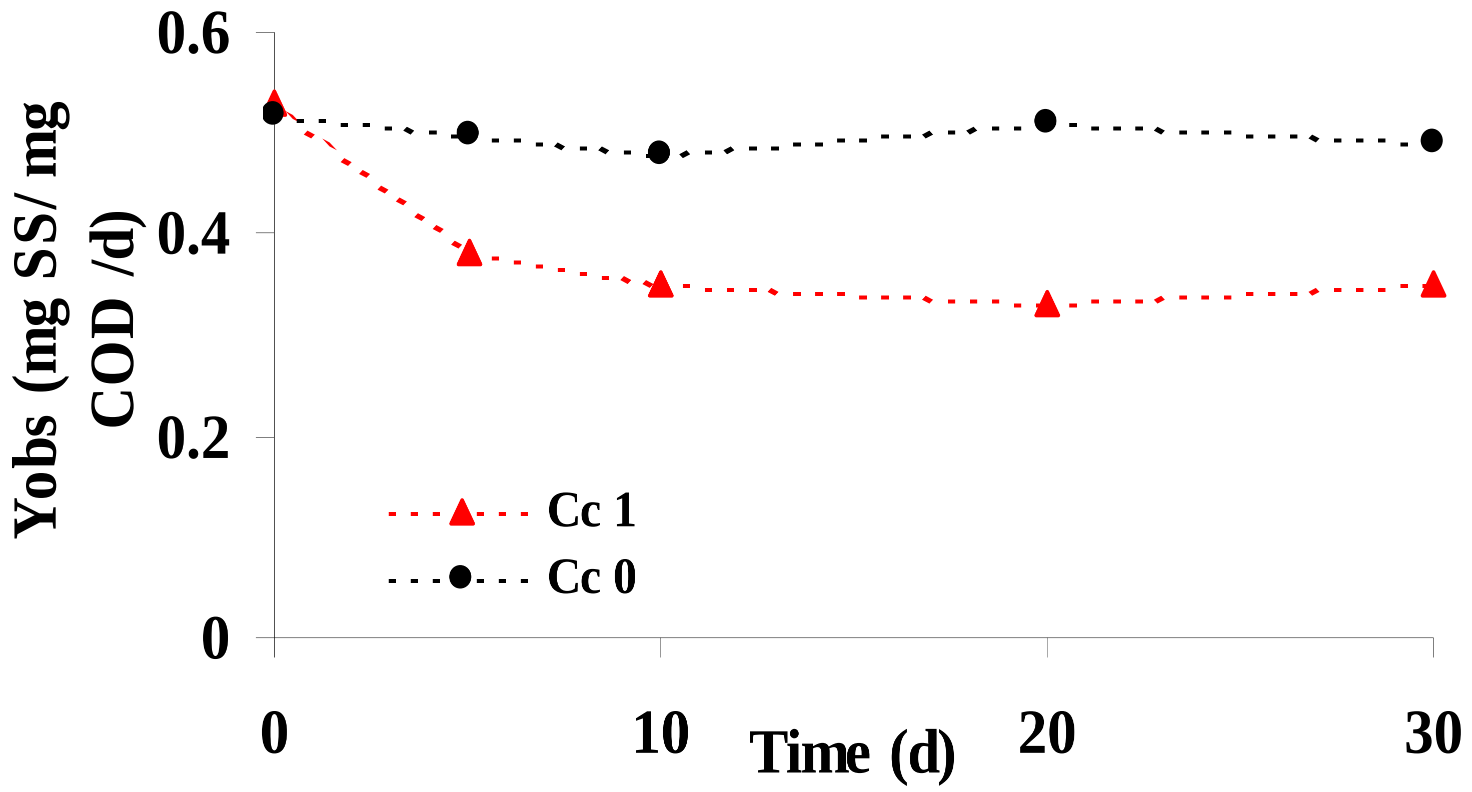
Observed Growth Yield of Batch Cultures Cultivated with TCS at Different Dosages



Effect of TCS on Cumulative Excess Sludge Production of Continuous Cultures

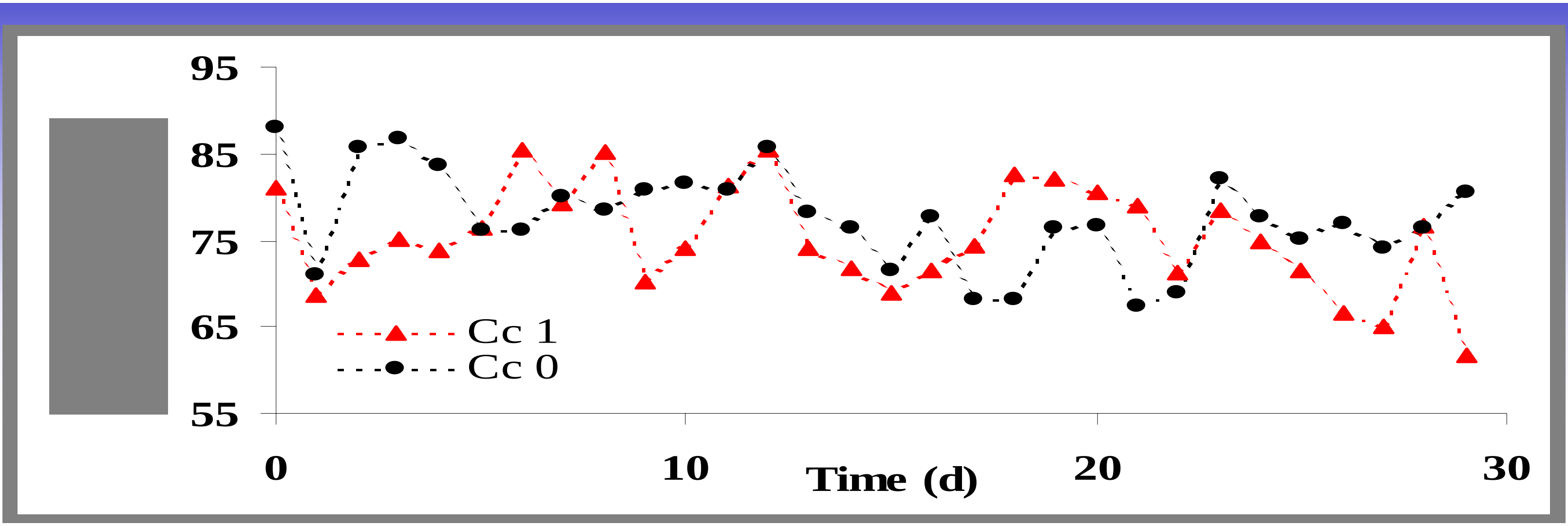


Observed Growth Yield Analysis of Continuous Cultures



- Experiments were conducted at a period of 3 hours
- During the experiment, TCS was not added

Effect of TCS on Substrate Removal Efficiency of Continuous Cultures



Parameter	TCS dose (ppm)	
	0	1.0
Mean Substrate removal (mg COD /L /d)	920	880
Daily Sludge Production	383	238
Overall yield (g SS / g COD)	**0.41**	**0.27**
Effluent SS conc. (mg/L)	**35.7±15.4**	**43.3±23.1**

Effect of TCS on SOUR of Batch and Continuous Cultures

Measurement Day	SOUR (mg O_2/g SS/hr)		
	0ppm TCS (control)	0.5ppm TCS	1.0ppm TCS
0	58.6	61.2	58.9
5th	52.1	57.1	49.3
10th	63.1	75.3	97.0
20th	63.7	79.7	90.8
30th	60.1	81.3	96.1

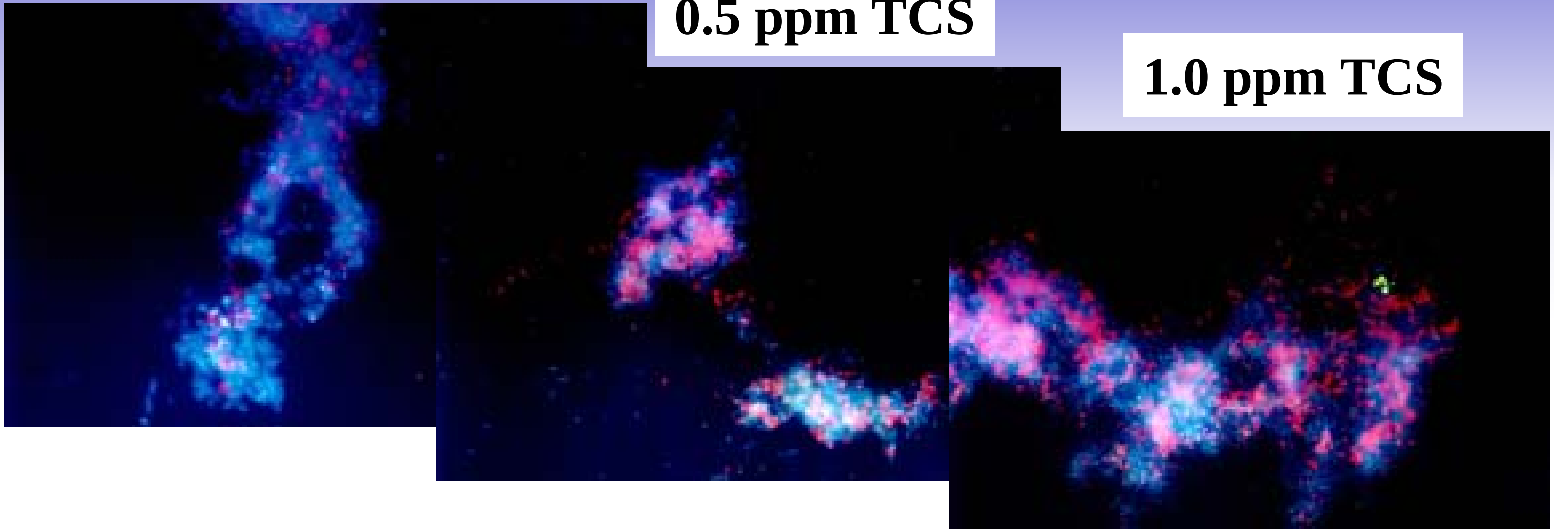
Batch Culture

INCREASE

Measurement Day	SOUR (mg O_2/g SS/hr)	
	0 ppm TCS (control)	1.0 ppm TCS
0th	61.2	63.7
5th	62.2	72.4
10th	66.7	77.8
20th	64.8	79.5
30th	62.6	78.3

Continuous Culture

Microbial Activity of Batch Cultures (DAPI & CTC Data)



Control

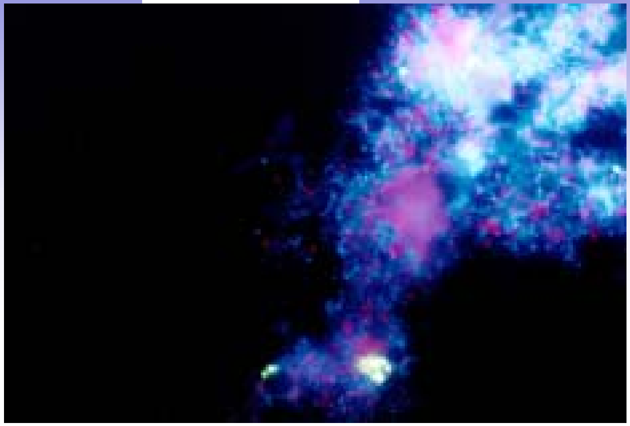
0.5 ppm TCS

1.0 ppm TCS

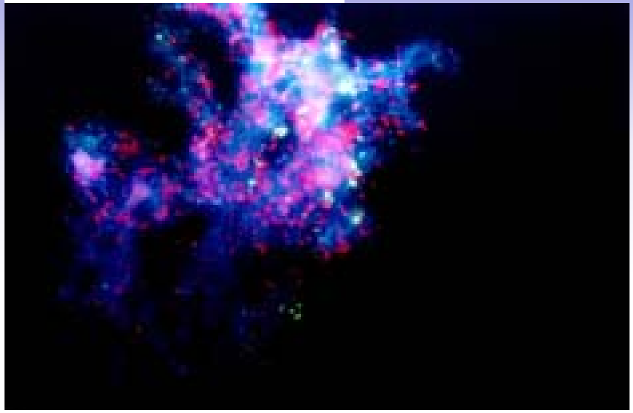
Day	Batch Culture	Active microbial portion (%)		no. of active microbes/ VSS (no./mg)	
15	*Control*	5.7	↓ Increase	1.39×10^8	↓ Increase
	0.5 ppm TCS	10.3		3.45×10^8	
	1.0 ppm TCS	10.5		4.07×10^8	
30	*Control*	3.9		1.09×10^8	
	0.5 ppm TCS	4.3		1.22×10^8	
	1.0 ppm TCS	7.6		2.72×10^8	

Microbial Activity of Continuous Culture

Control



1.0 ppm TCS

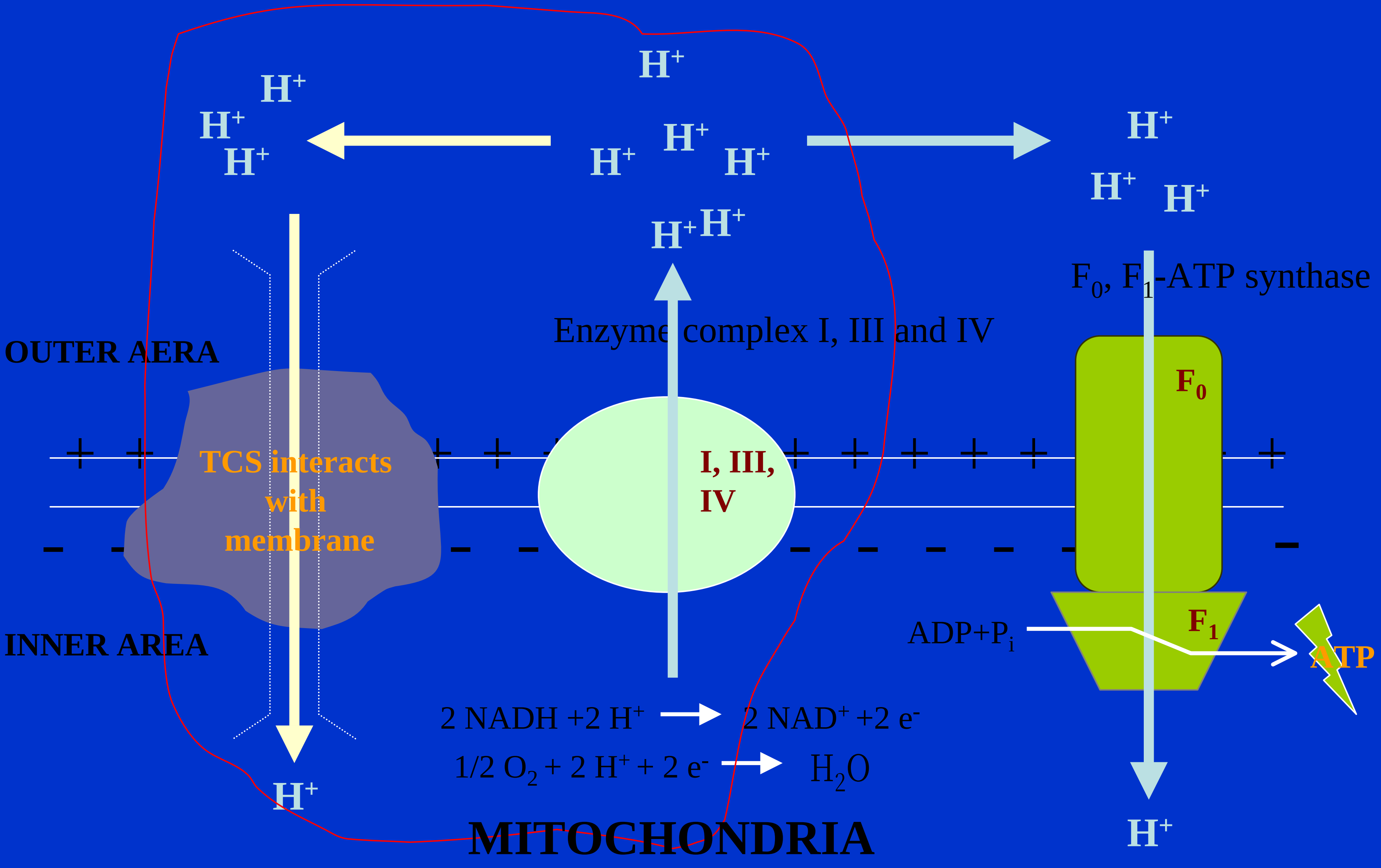


Day	Continuous Culture	Active microbial portion (%)	no. of active microbes/ VSS (no./mg)
15	*control*	7.4	1.49×10^8
	1.0 ppm TCS	11.2	2.99×10^8
30	*control*	5.6	1.42×10^8
	1.0 ppm TCS	10.1	2.69×10^8

Increase

Increase

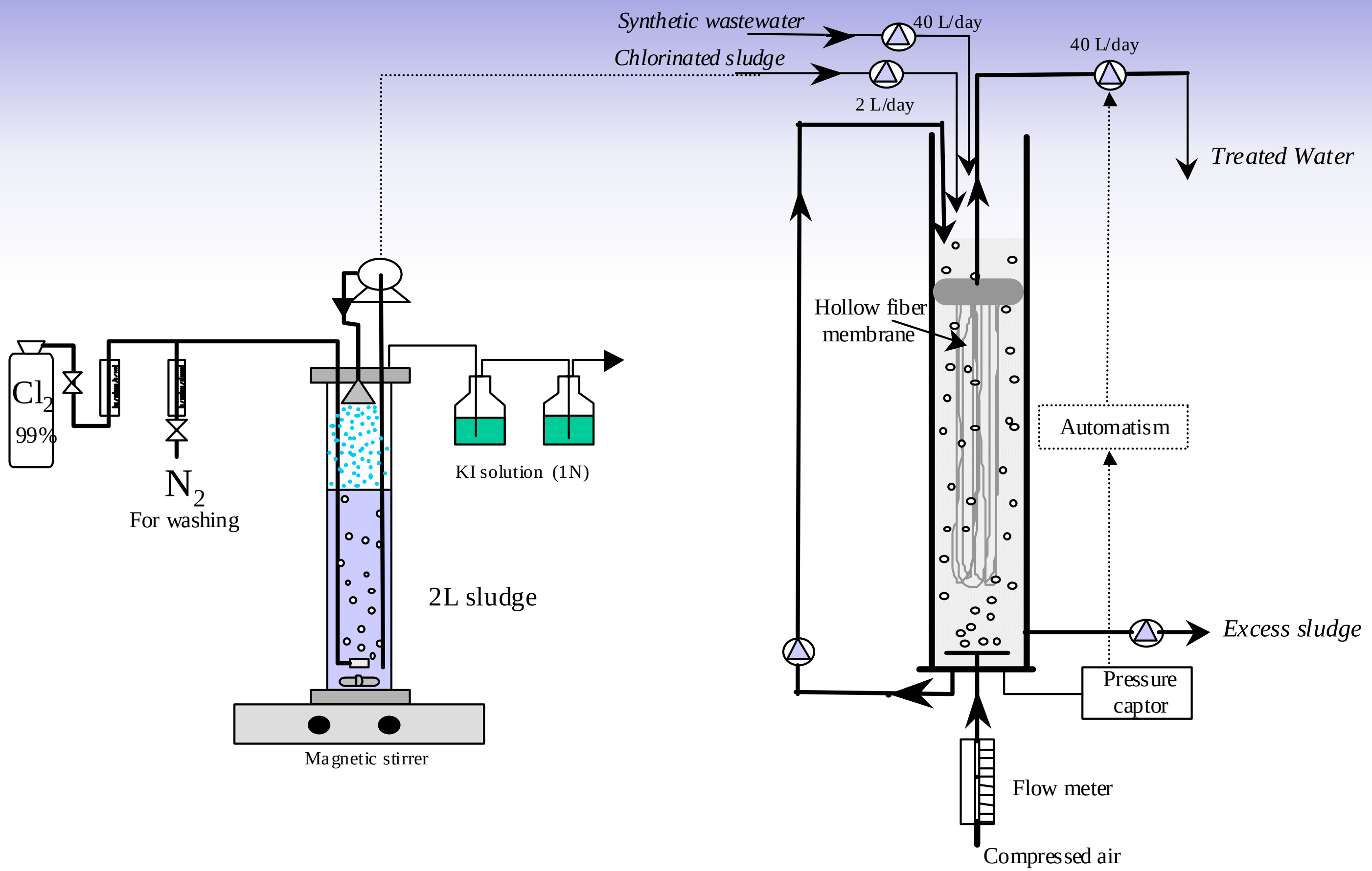
Proposed Mechanism: Futile Cycle Induced by TCS



$2\ NADH + 2\ H^+ \rightarrow 2\ NAD^+ + 2\ e^-$

$1/2\ O_2 + 2\ H^+ + 2\ e^- \rightarrow H_2O$

[2] Chlorination pretreatment of Excess Sludge



Ⓑ **Reactor for sludge chlorination**

Ⓐ **Membrane bioreactor**

Figure 2-1. Membrane biological reactor (A) and chlorination setup (B) used in this study.

Chlorine dose and residual during the sludge chlorination.

Chlorine Dose	**Free Cl_2 Residual**	**Total Cl_2 residual**
(g Cl_2 /g MLSS)	(mg Cl_2/L)	(mg Cl_2/L)
0.066	0.3	5.5
0.133	0.3	9.0
0.199	1.8	12.9
0.266	5.8	37.8
0.332	19.1	65.0

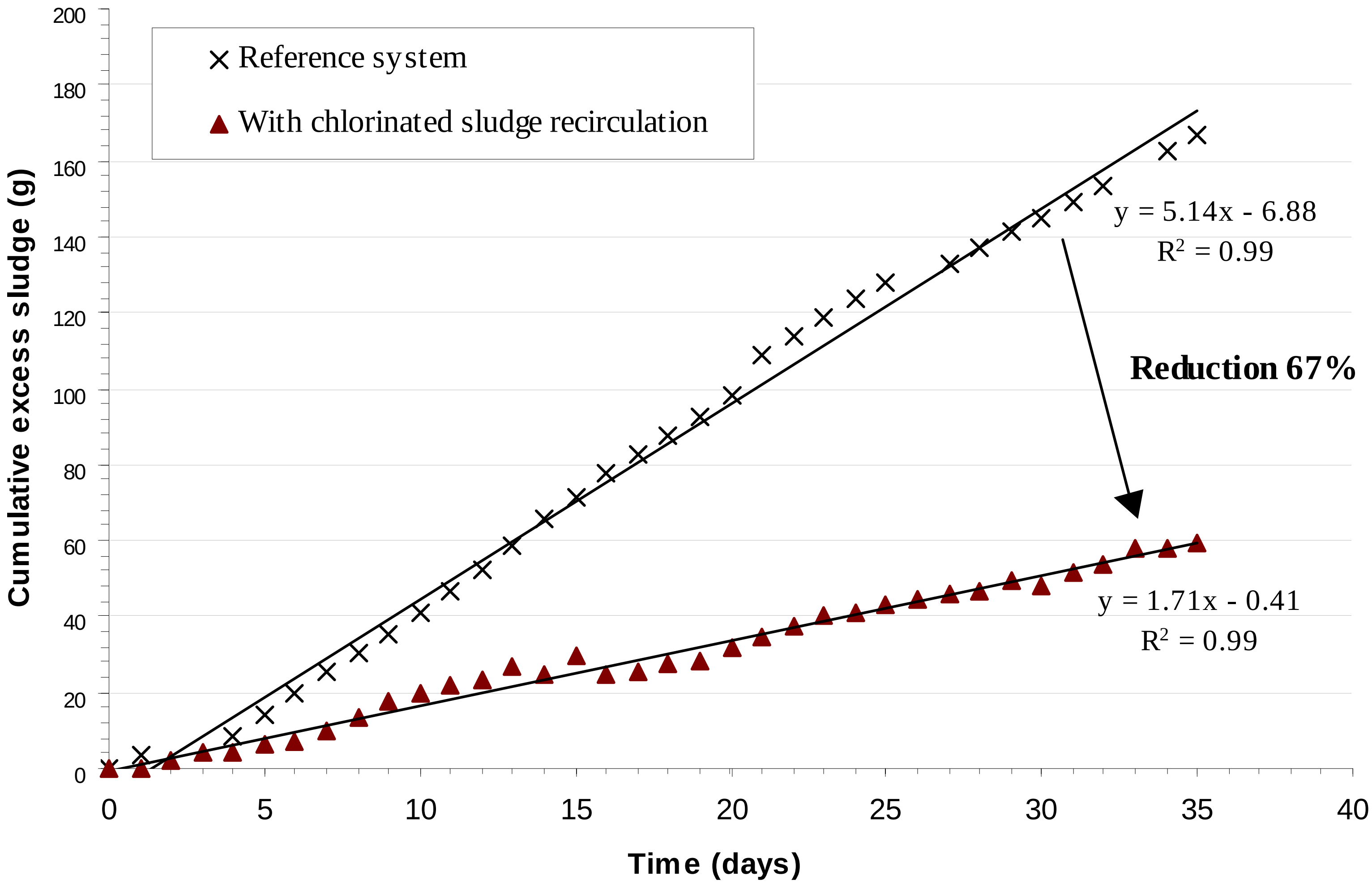


Figure 2-2. Sludge production rates in the continuous systems without (the reference system) and with (testing line) the chlorination treatment of excess sludge.

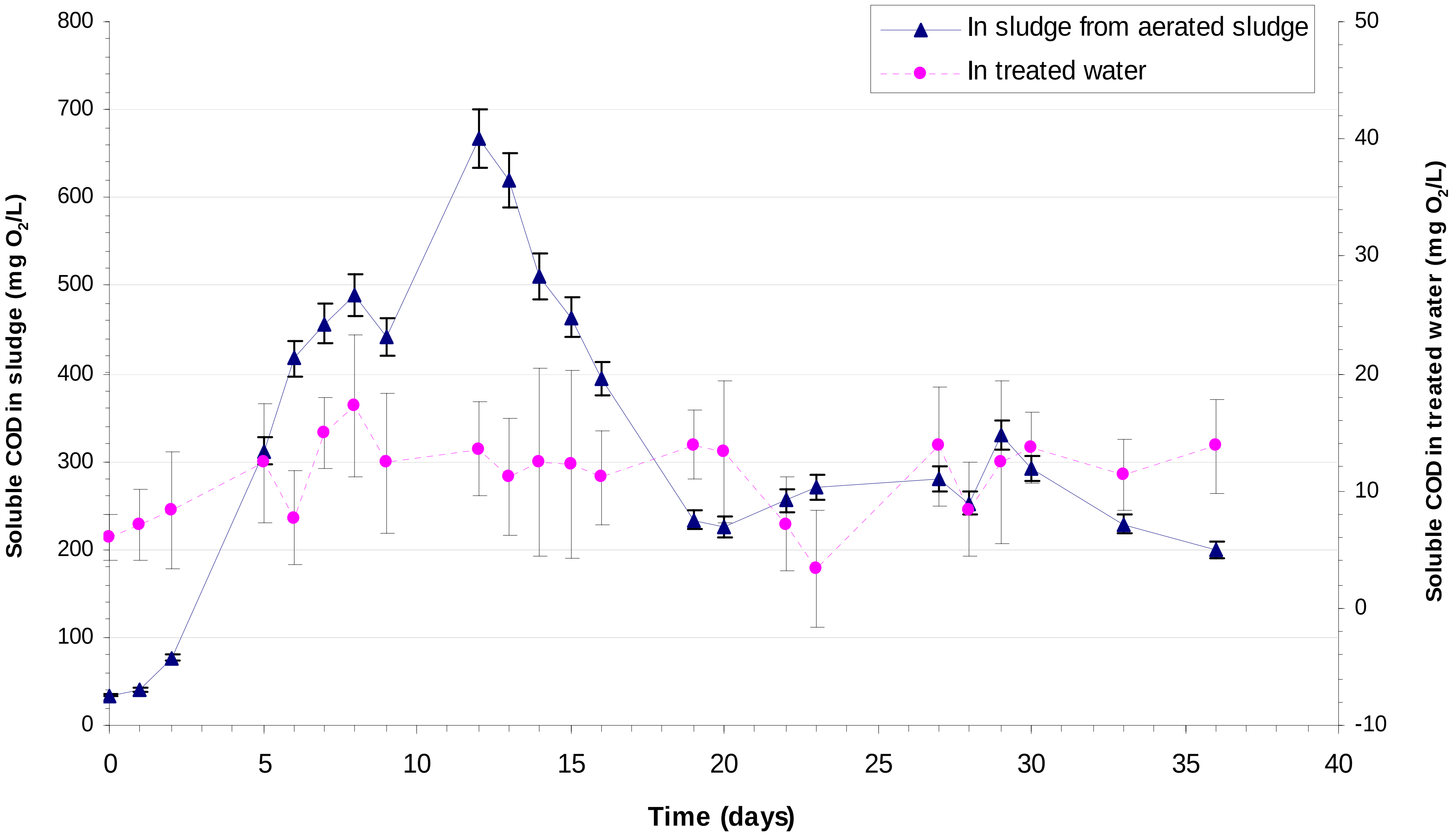


Figure 2-3. Variations of the COD concentration in the sludge and treated water of the testing system.

(Errors bars present the standard deviation of the COD measurement).

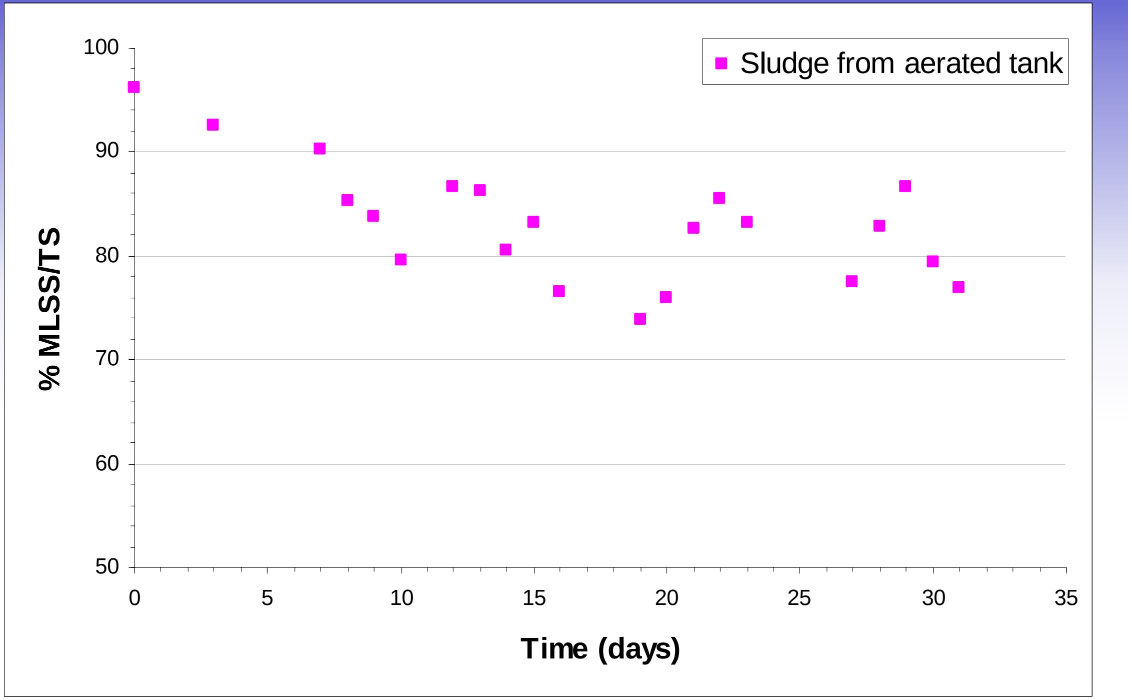


Figure 2-4. Change of MLSS/TS during the operation of the testing system.

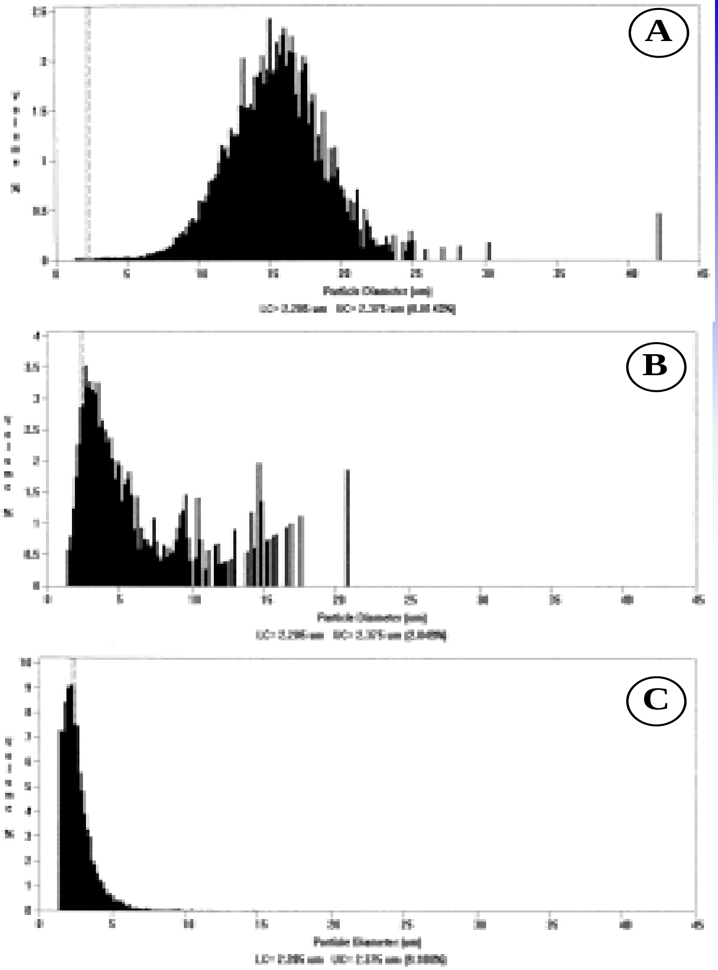


Figure 2-5. Particle distribution in activated sludge

(A) prior to chlorination study;

(B) after recirculation of chlorinated excess sludge for 20 days;

(C) just after chlorination step.

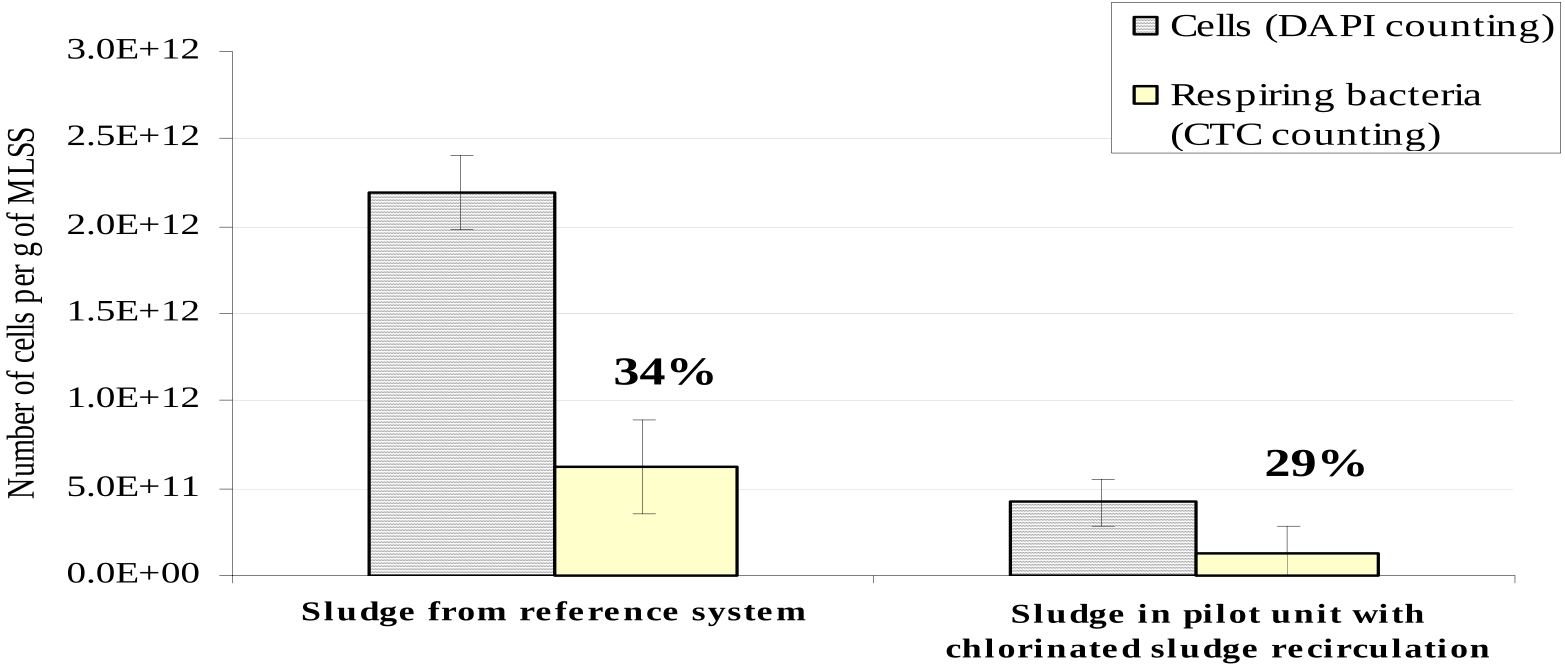
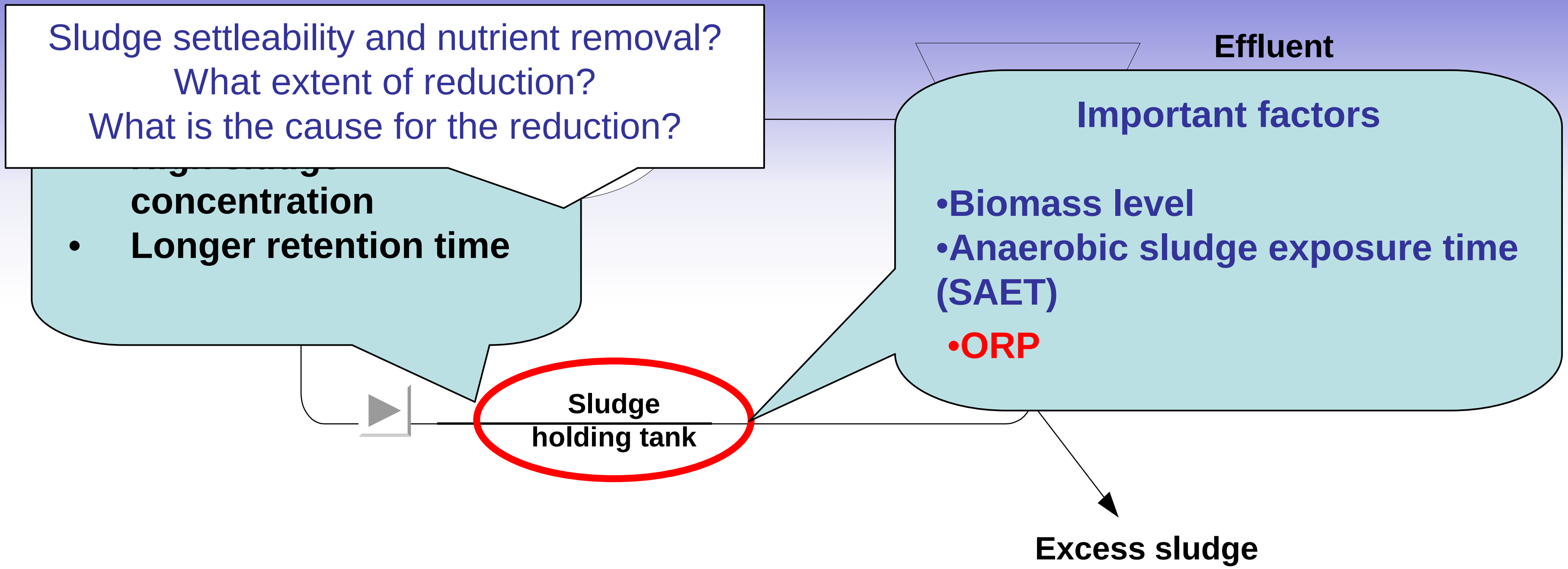


Figure 2-8. Total number of cells and the number of active bacteria in both the reference and testing systems (the results represent the mean values of five independent analyses).

THMs concentrations in the treated water and sludge.

	THMs concentration (μg/L)			
Sample	*Analysis 1*	*Analysis 2*	*Analysis 3*	*Analysis 4*
Treated water	<200	<200	<200	<200
Chlorinated sludge (just after chlorination)	260*	<200	310	270*
Chlorinated sludge (after 10 min reaction)	<200	230*	<200	<200
Sludge after NaClO addition (150 mg Cl_2/L)	1280	830	680	860

[3] Oxic-Settling-Anaerobic (OSA) System



Sludge settleability and nutrient removal?
What extent of reduction?
What is the cause for the reduction?

concentration
- Longer retention time

Important factors

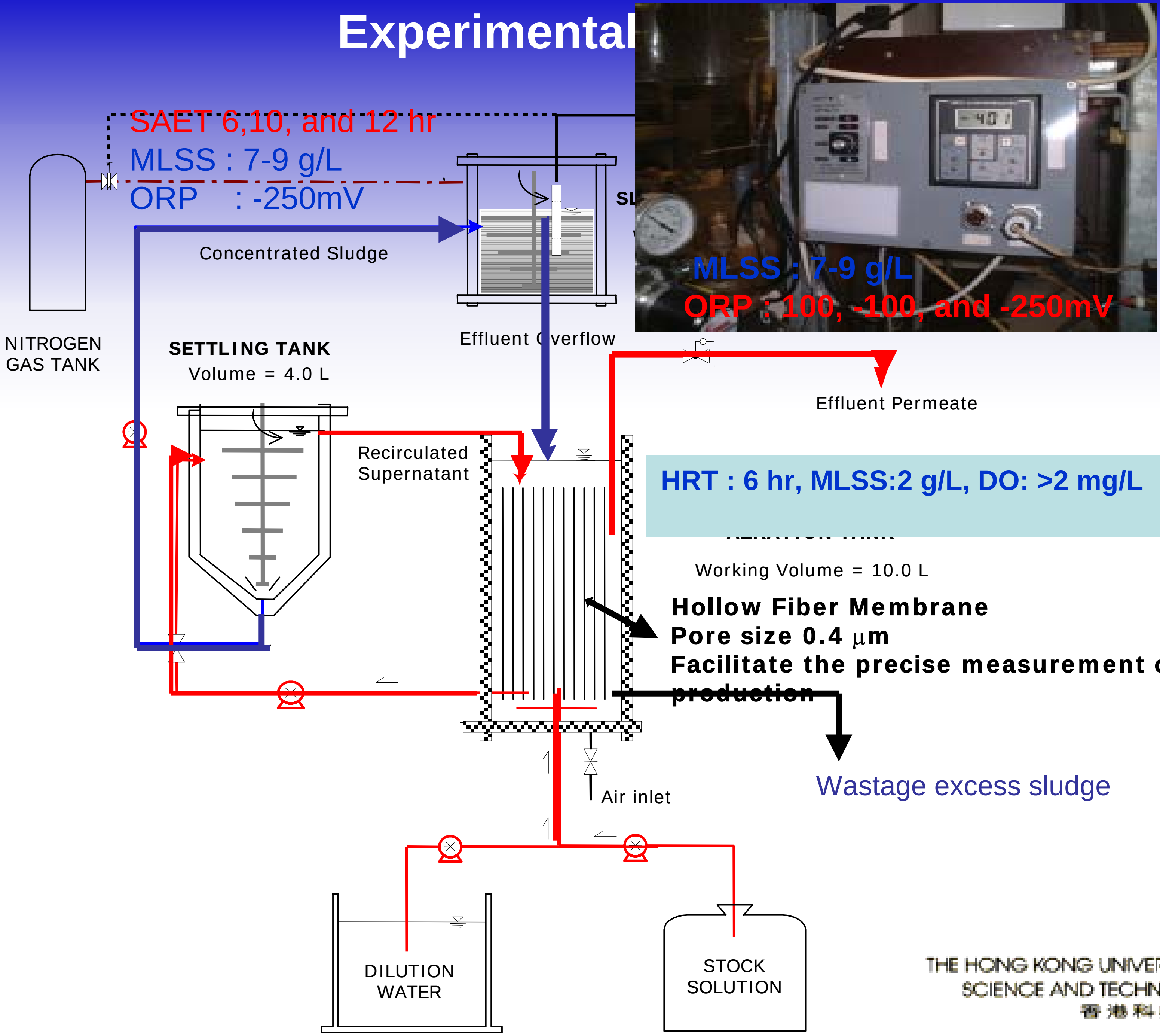
- **Biomass level**
- **Anaerobic sludge exposure time (SAET)**
- **ORP**

- **It is relatively easy to modify conventional activated sludge process**
- **Neither chemical addition nor heat energy is required**
- **The treatment efficiency is NOT affected**
- **Great potential in full-scale application**

Study Objectives

- To examine the capacity of OSA system in reducing excess sludge production
- To investigate the performance of an OSA system under different operating conditions
- To study the impact of the anaerobic sludge zone on bacterial activity
- To identify the cause of the reduction of excess sludge production in an OSA system

Experimental



SAET 6,10, and 12 hr
MLSS : 7-9 g/L
ORP : -250mV

MLSS : 7-9 g/L
ORP : 100, -100, and -250mV

HRT : 6 hr, MLSS:2 g/L, DO: >2 mg/L

Hollow Fiber Membrane
Pore size 0.4 µm
Facilitate the precise measurement of sludge production

Wastage excess sludge

Observed Growth Yield at Different ORP in Sludge Holding Tank

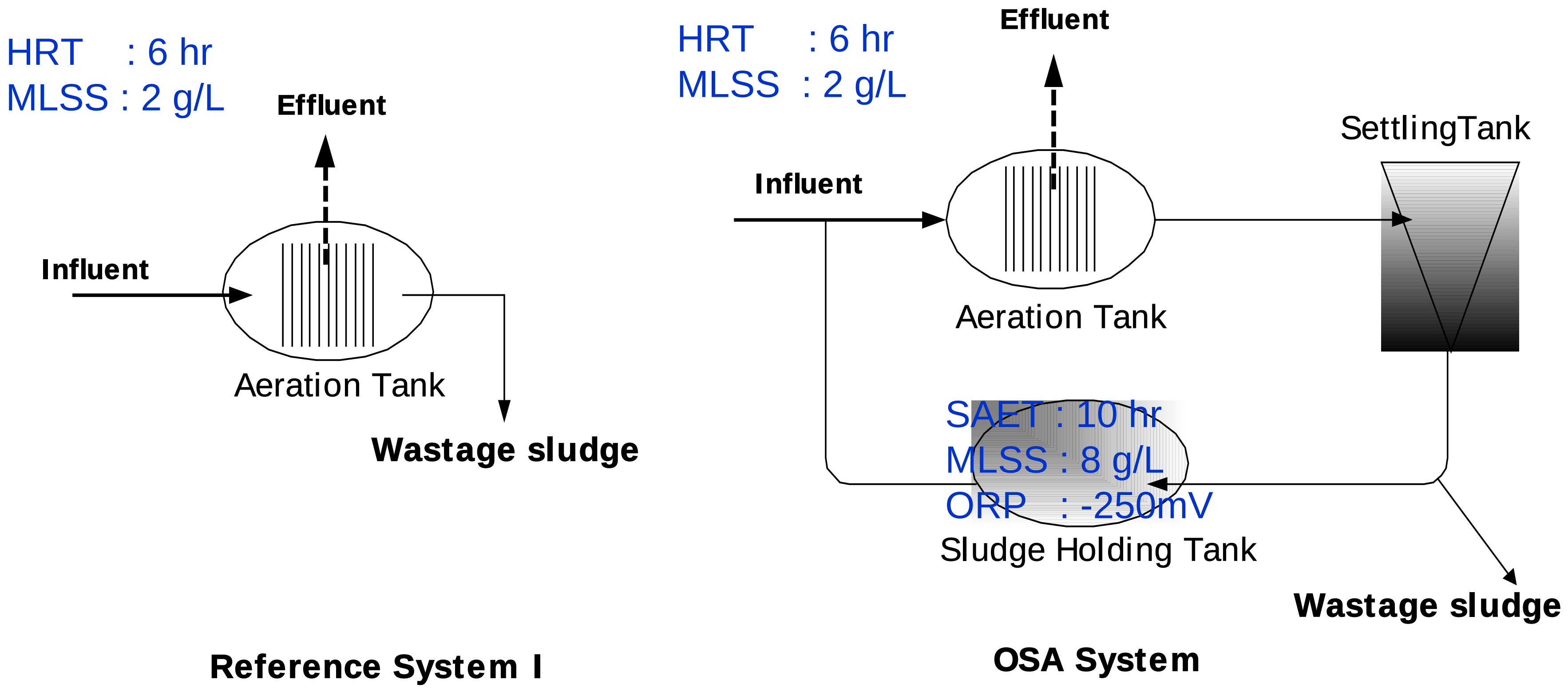
ORP in sludge holding tank (mV)	Net sludge production rate (g SS/day)	COD removal rate (g COD/day)	Y_{obs} (g SS/g COD)
+ 100	3.90	12.18	0.32
-100	2.70	12.27	0.22
-250	2.30	12.77	0.18

Observed growth yield
at different SAET in Sludge Holding Tank
at -250 mV ORP

SAET in sludge holding tank (hours)	Net sludge production rate (g SS/day)	COD removal rate (g COD/day)	Y_{obs} (g SS/g COD)
6	3.5	12.2	0.27
10	2.4	12.3	0.19
12	2.0	12.7	0.17

Comparisons of Performance of OSA System with Reference System under same COD Loading

Operating conditions



HRT : 6 hr
MLSS : 2 g/L

Reference System I

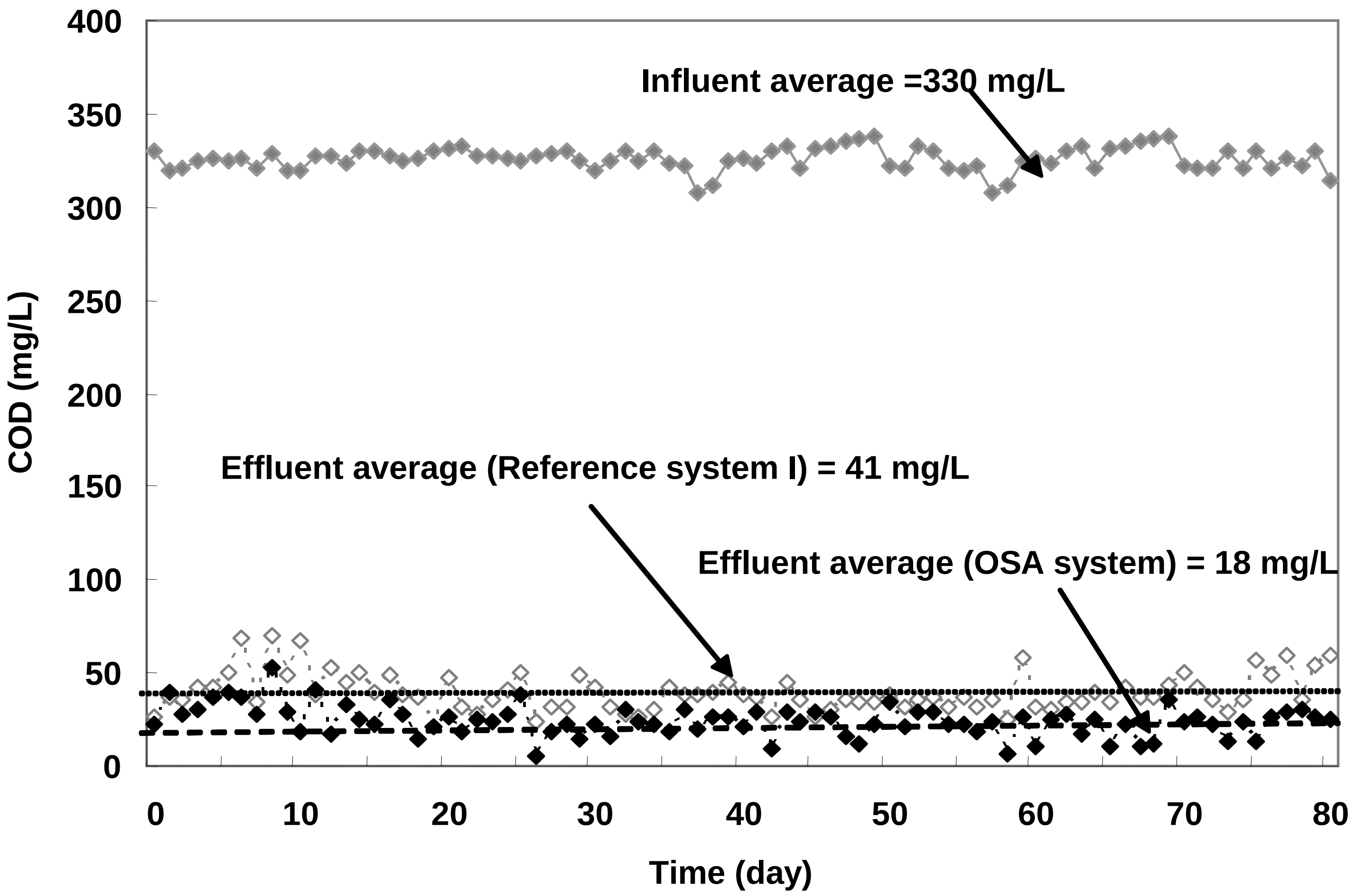
HRT : 6 hr
MLSS : 2 g/L

SAET : 10 hr
MLSS : 8 g/L
ORP : -250mV

OSA System

Membrane filtration was used to facilitate the precise measurement

COD Removal

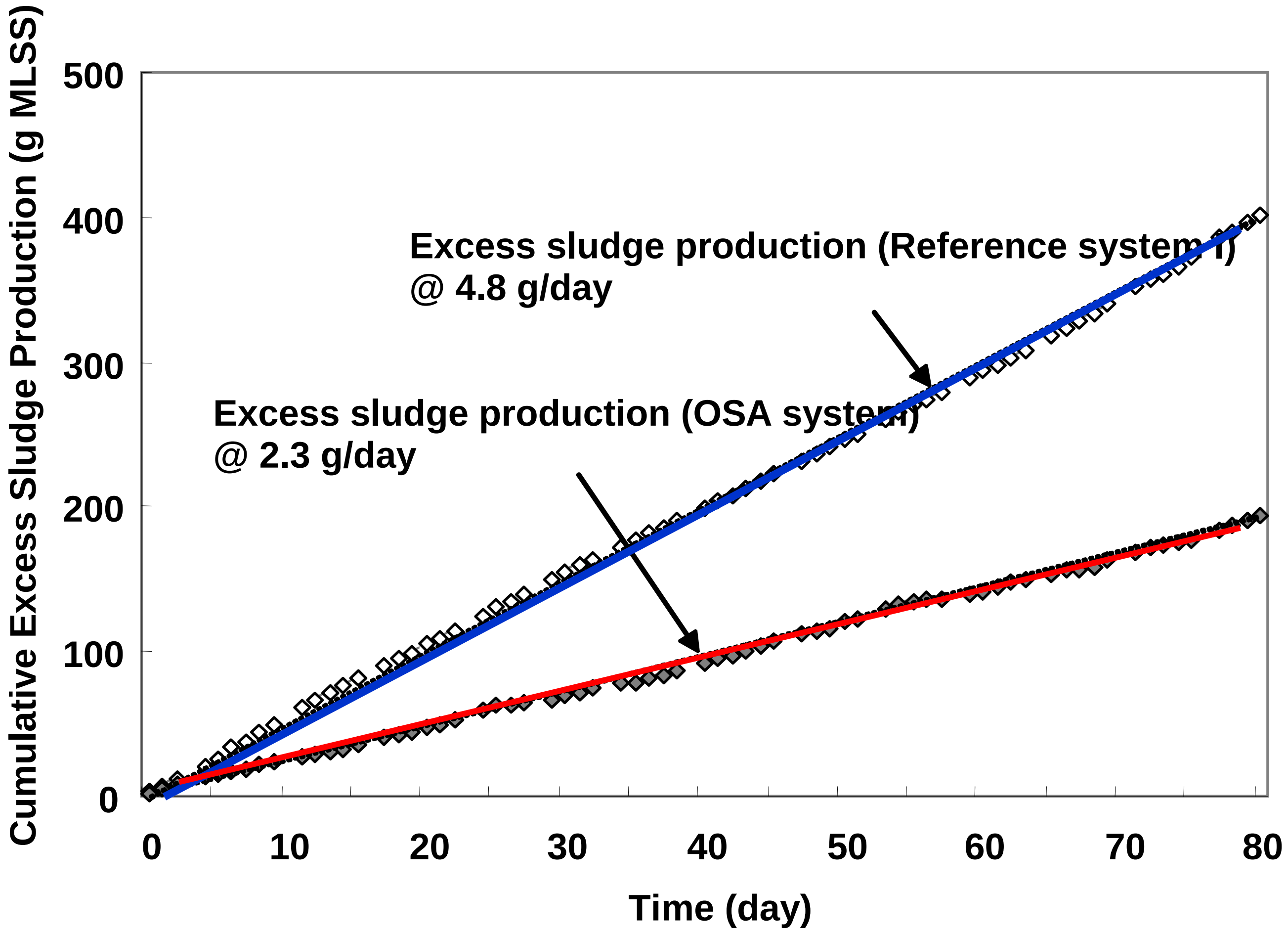


Influent average =330 mg/L

Effluent average (Reference system I) = 41 mg/L

Effluent average (OSA system) = 18 mg/L

Sludge Production Rate

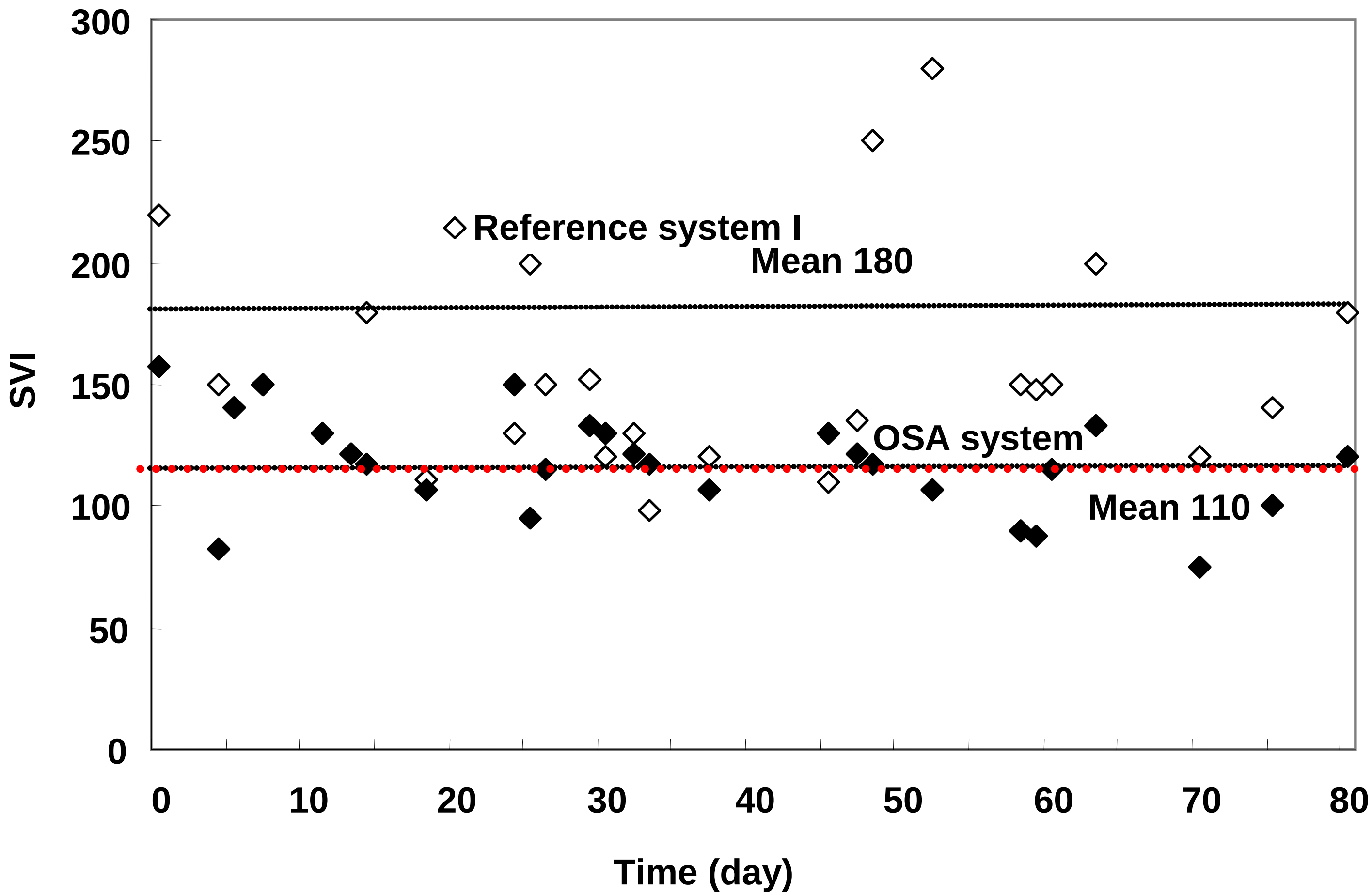


Observed Growth Yield

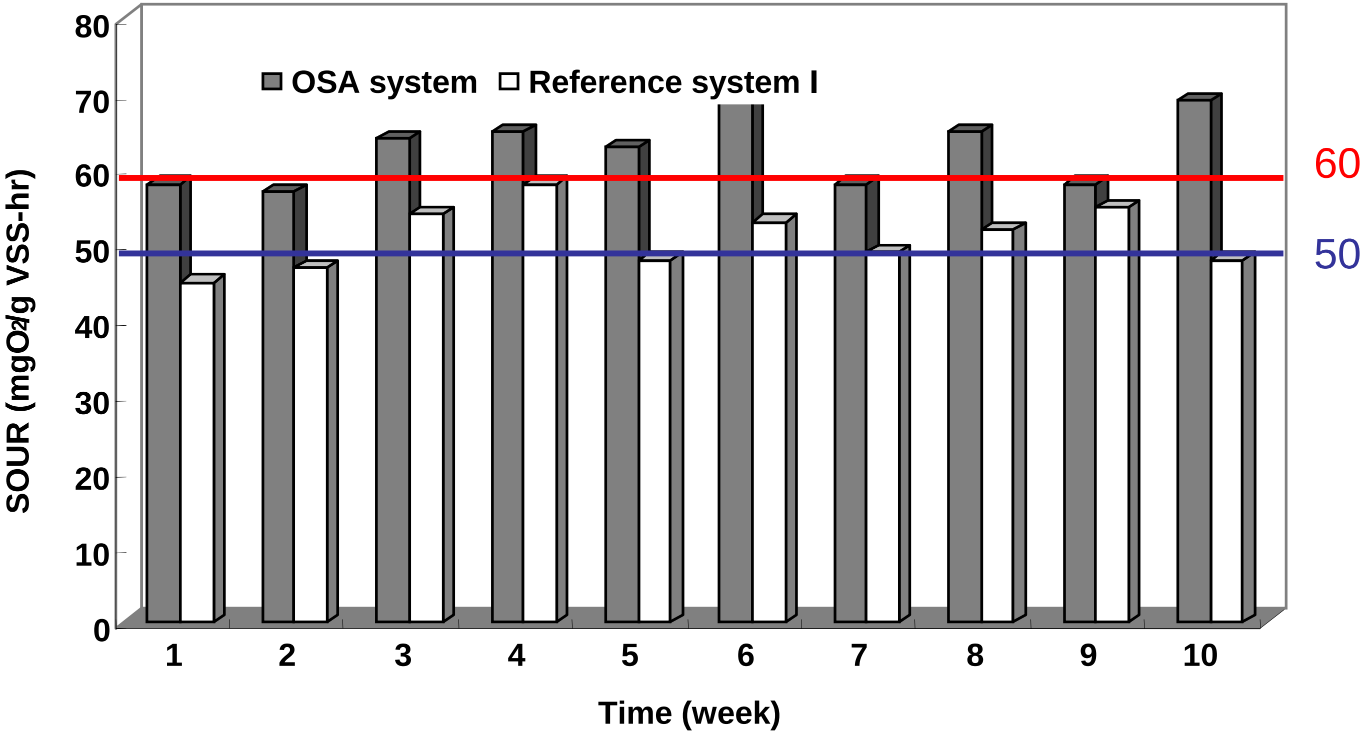
	Reference System I	OS
Net sludge production rate (g SS/day)	4.8	
Substrate utilization rate (g COD/day)	12	
Y_{obs} (g SS/g COD)	0.4	0.2

50 % of reduction !!!
How about the sludge settleability and bacteria activity?

Sludge Settleability



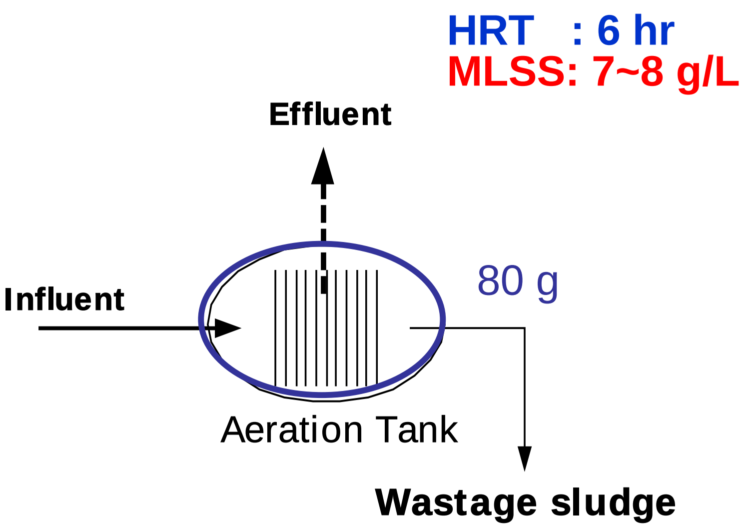
SOUR



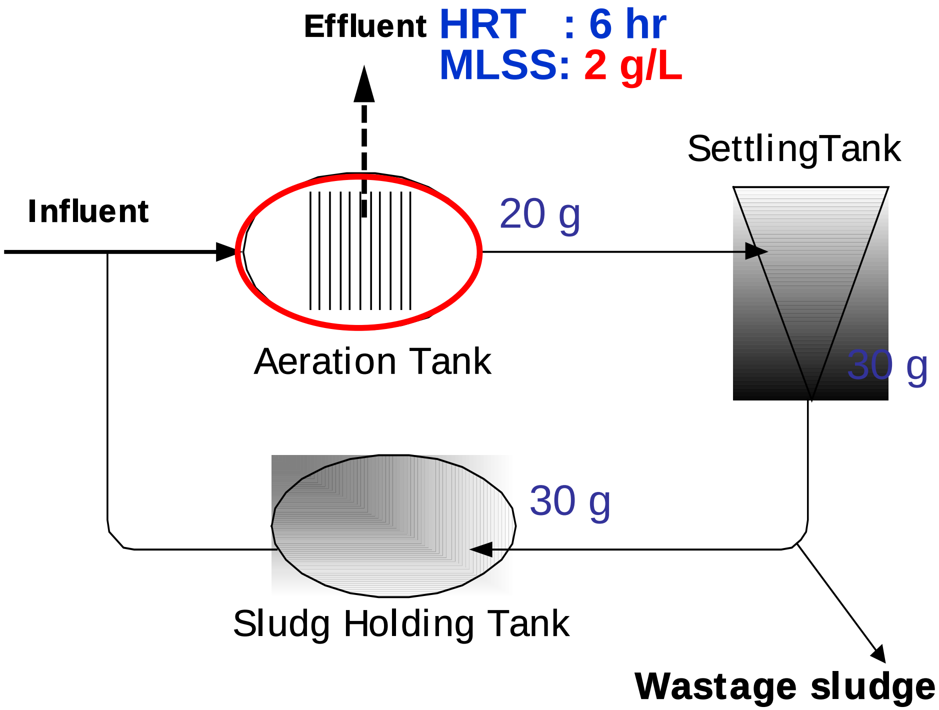
At temperature 20ºC

Comparisons of Performance of OSA System with Reference System under same Sludge Quantity

Operating Conditions



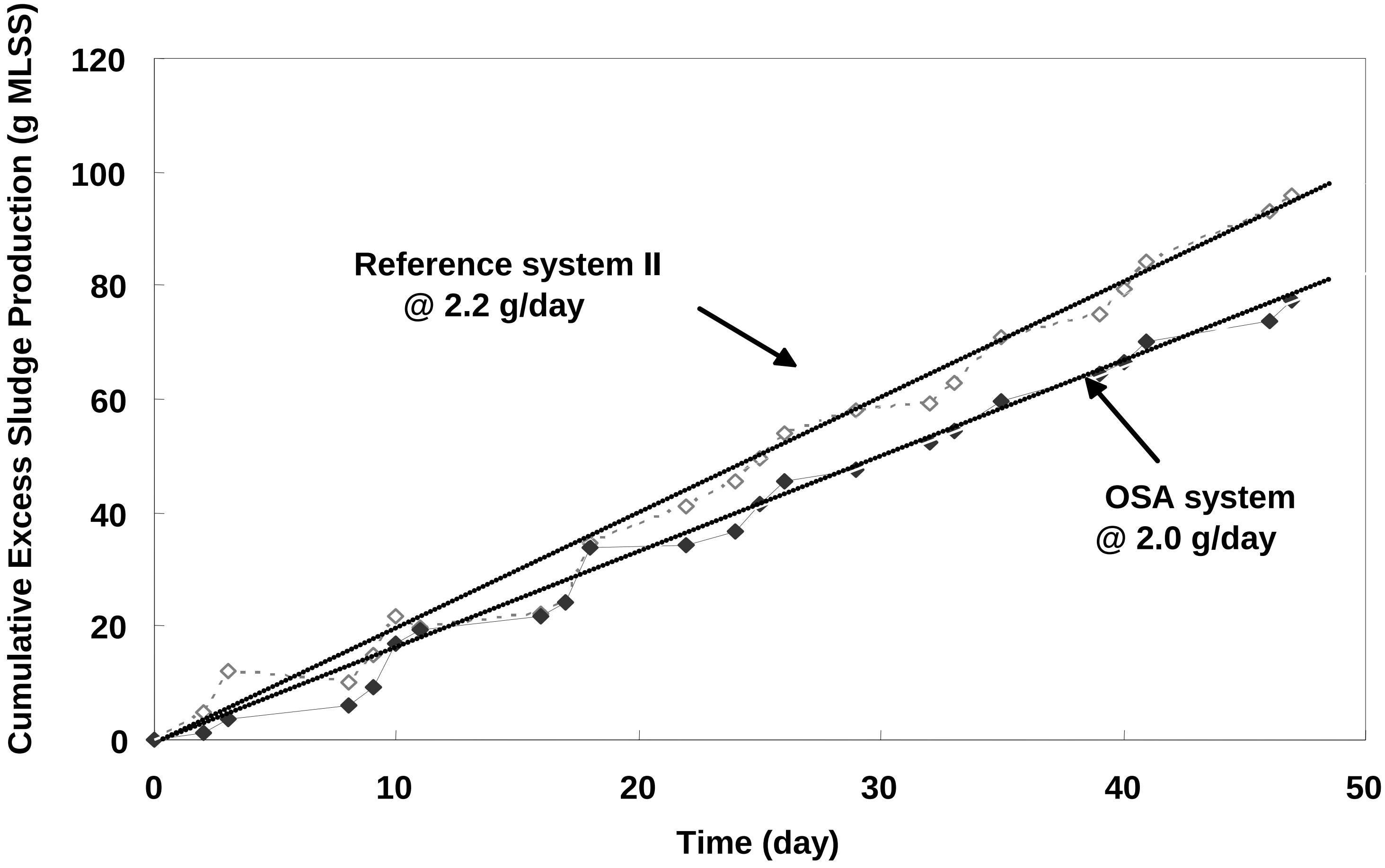
Reference System II



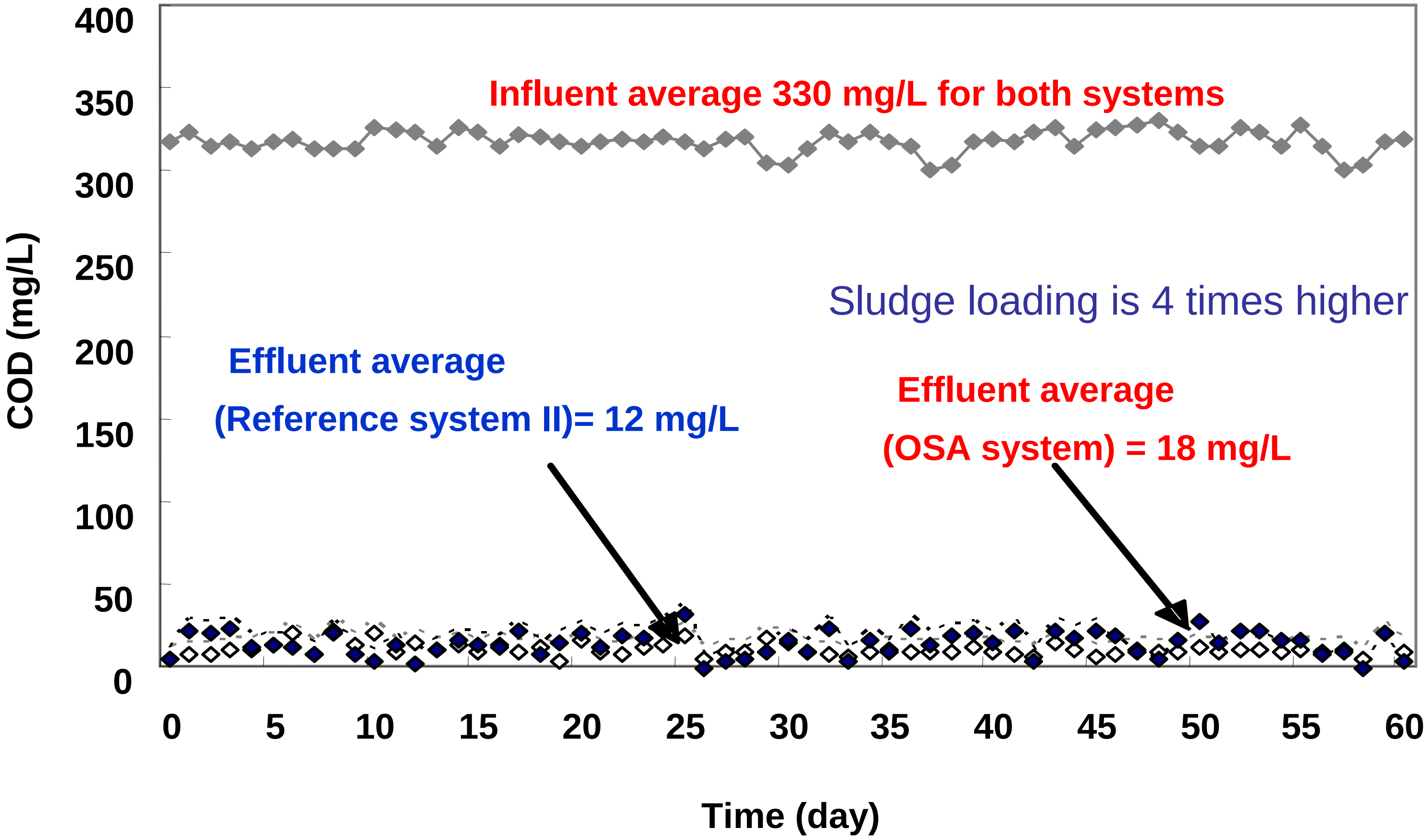
OSA System

Higher sludge quantity will generally result in low sludge production? → is it the main cause for the OSA system for reducing the excess sludge production?

Sludge Production Rate



COD Removal



Influent average 330 mg/L for both systems

Sludge loading is 4 times higher

Effluent average

(Reference system II)= 12 mg/L

Effluent average

(OSA system) = 18 mg/L

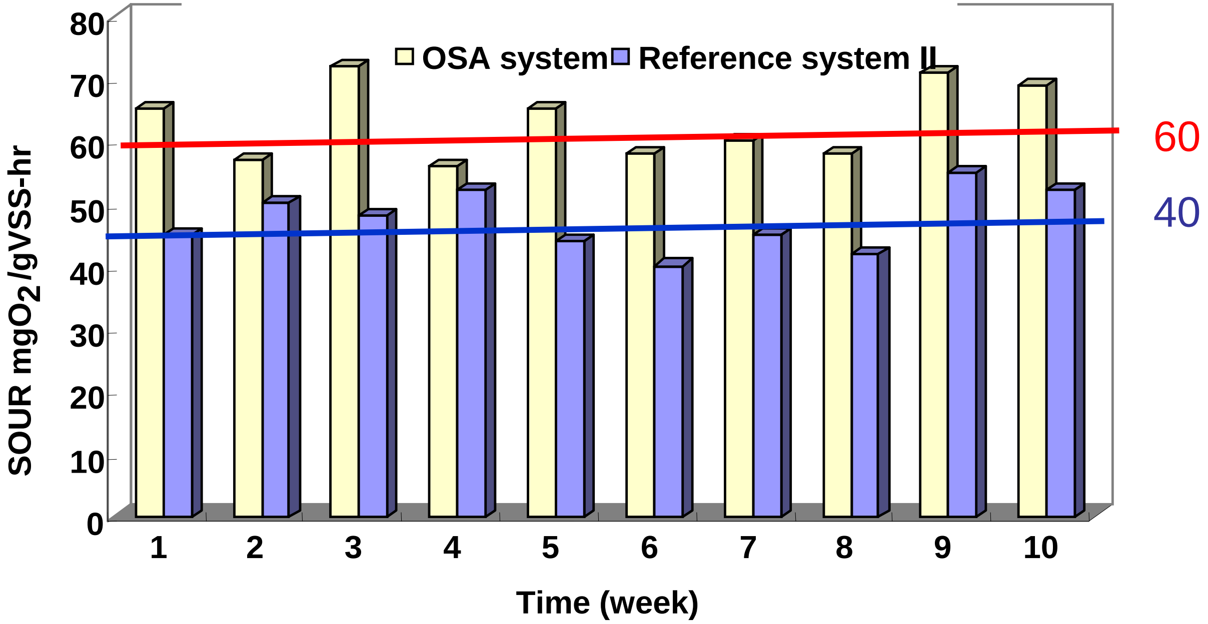
Observed Growth Yield

	Reference Sy	
Net sludge production rate (g SS/day)	2.2	
Substrate utilization rate (g COD/day)	13	
Y_{obs} (g SS/g COD)	0.2	0.18

However, the operating principle of the two systems are different !

Let’s look at the other parameters…

SOUR



Substrate oxidation and cell synthesis:

$$\text{COHNS} + O_2 + \text{nutrients} \xrightarrow{\text{bacteria}} CO_2 + H_2O + NH_3 + C_5H_7O_2N\,(\text{new cell tissue}) + \text{other end products}$$

At Temperature 20°C

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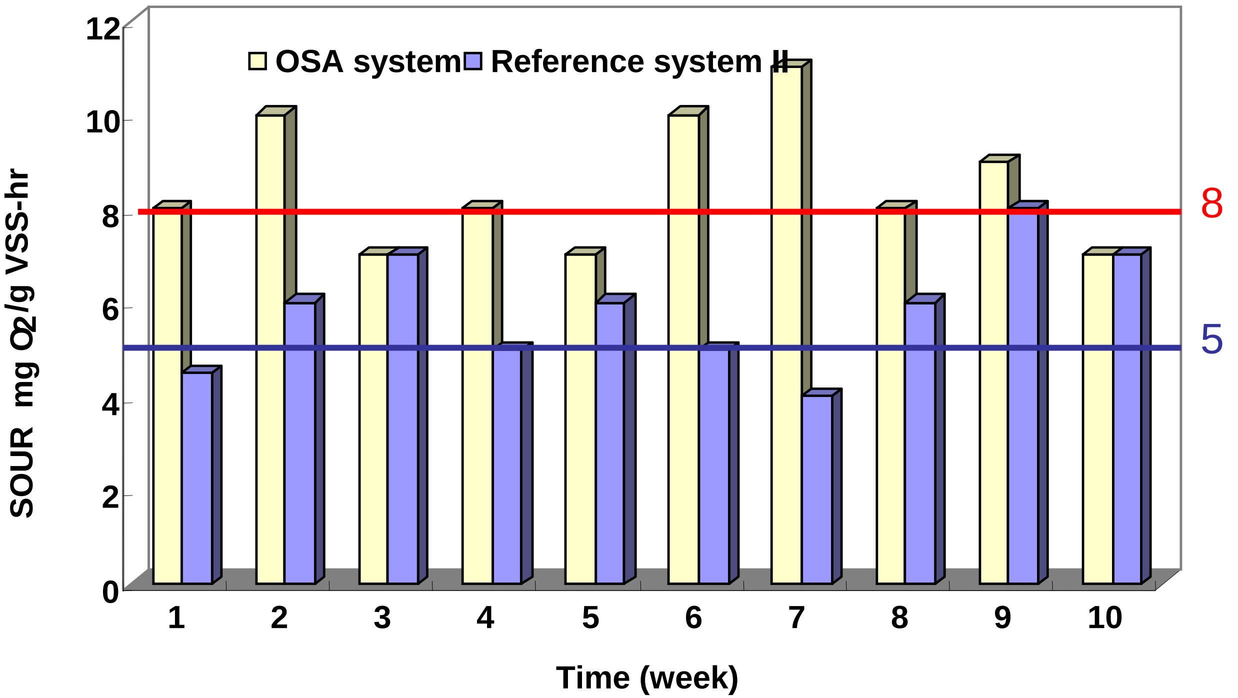
Endogenous Respiration



Endogenous respiration:

$$C_5H_7O_2N \text{ (Cells)} + 5\,O_2 \xrightarrow{\text{bacteria}} 5CO_2 + NH_3 + 2H_2O$$

At Temperature 20ºC

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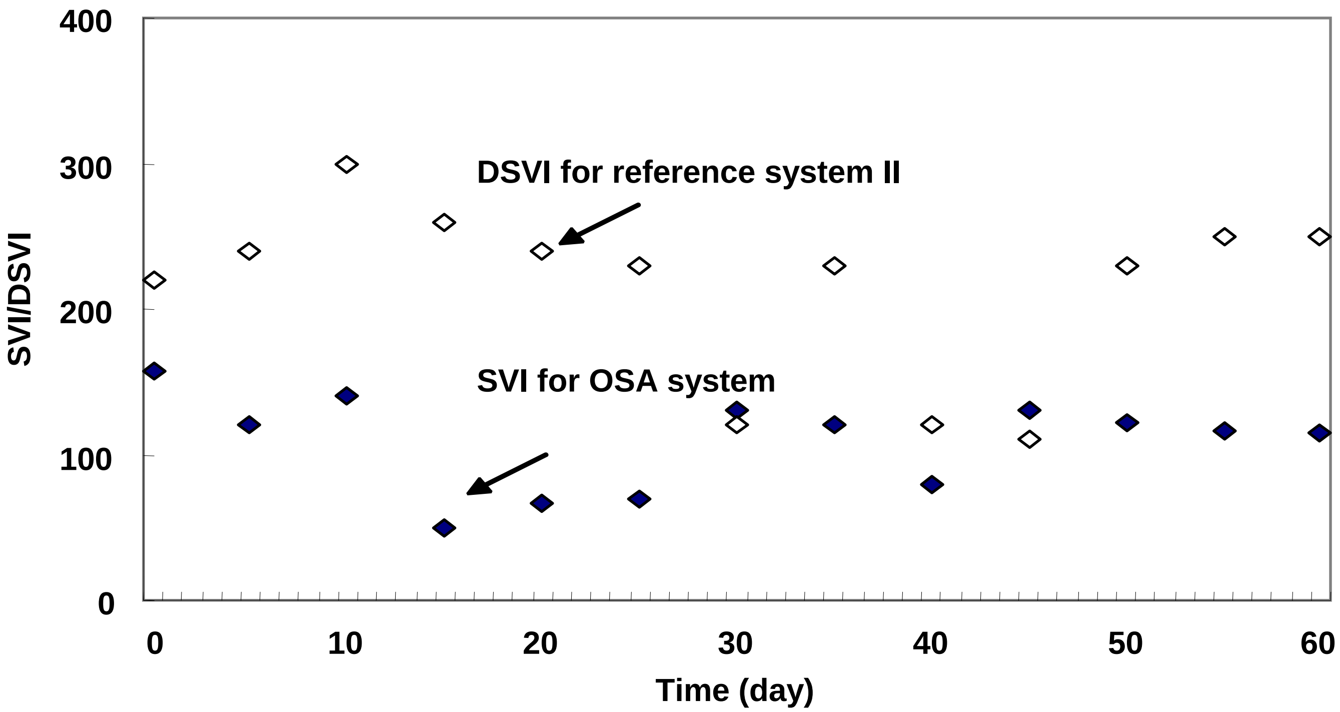
Sludge Settleability

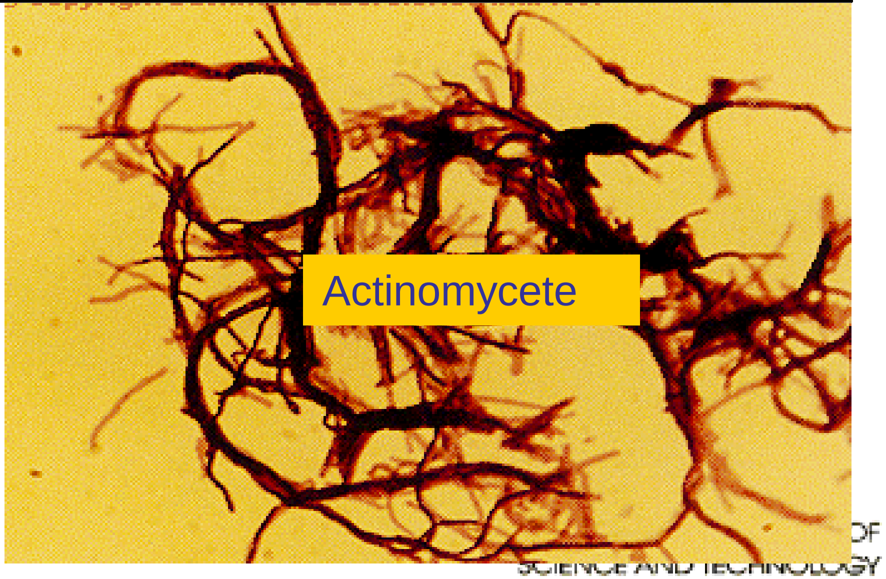
The diluted SVI (DSVI) test has been used for the reference system II since MLSS concentration in the aeration tank was very high (Wastewater Engineering 4th edition)



Microscopic Observation

Type of microorganism	OSA System	Reference System II
Protozoa and metazoa (counts/mL)	absent	13,750
Actinomycete (CFU/mL)	<100	1,260

Ciliates in Ref II

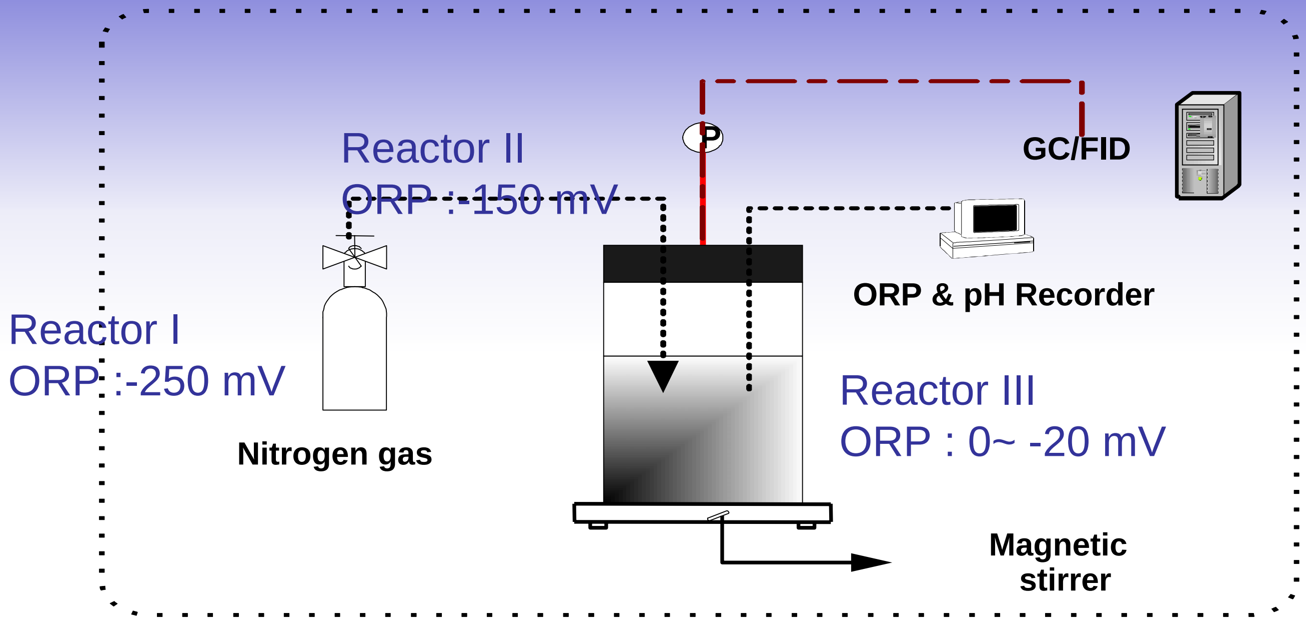


Actinomycete

Nutrients Removal

		Reference system II	OSA system	
Parameter	Influent	Effluent	System effluent	Effluent of the sludge holding tank
TN (mg N/L)	60±1	55±1	38±0.5	26±0.5
NH_4^+- (mg N/L)	35±0.5	0.04±0.5	0.04±0.05	25±0.5
NO_2^- (mg N/L)	0	0.05±0.02	0.05±0.05	0.02±0.005
NO_3^- (mg N/L)	1.6±0.3	55±1	36±1	0.2±0.05
PO_4^{3-} (mg P /L)	10±1	9.5±0.5	5.5±1	45±2
COD (mg/L)	330±10	12±2	18±2	80±3

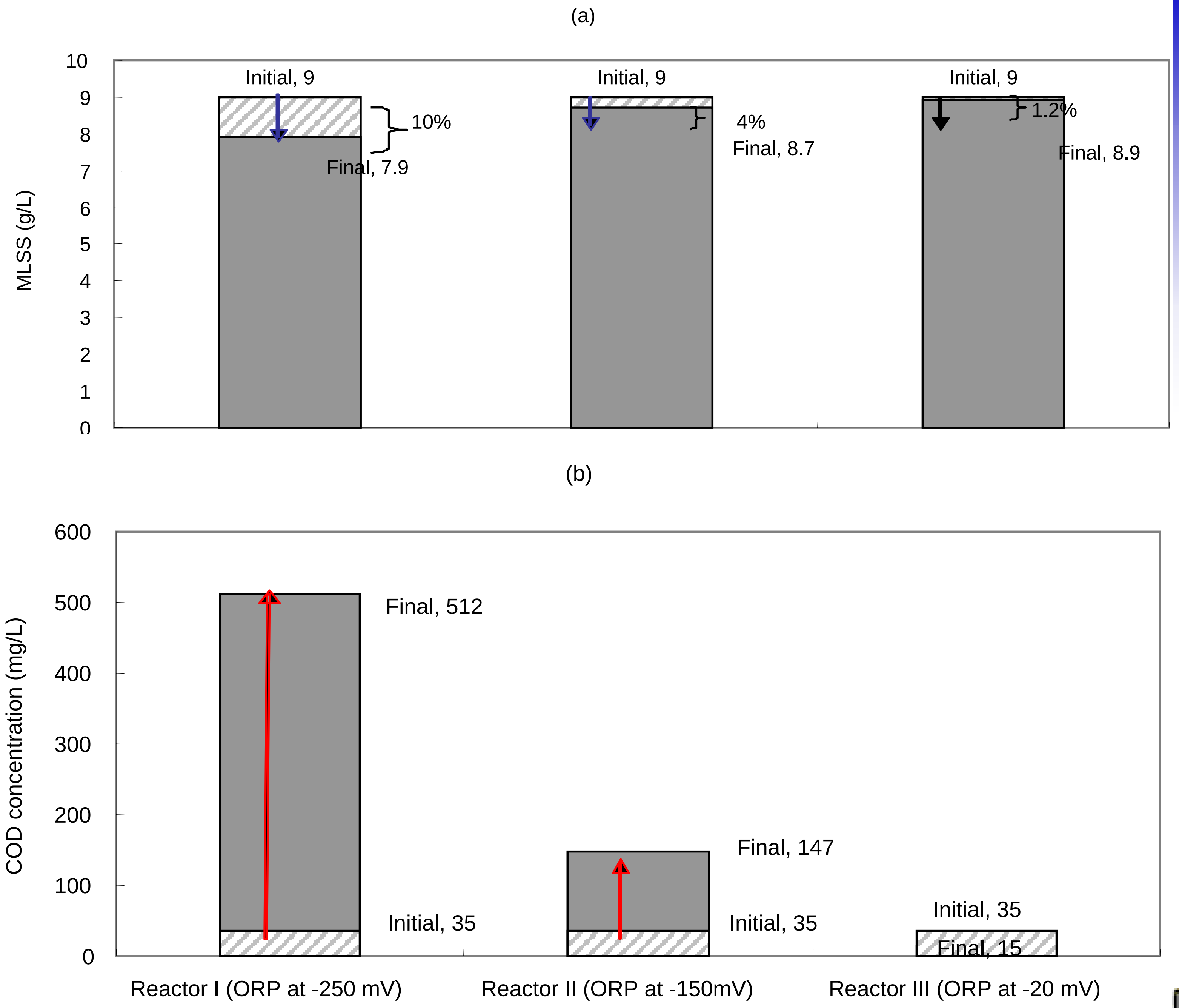
COD Balance Batch Test Set-Up



Measured Parameters

- **pH and ORP**
- **MLSS and COD**
- **Nitrite, Nitrate, Phosphate, Sulfate**
- **Organic Carbon content in the produced gas**

MLSS and COD


(a)
MLSS (g/L)
10
9
8
7
6
5
4
3
2
1
0
Initial, 9
10%
Final, 7.9
Initial, 9
4%
Final, 8.7
Initial, 9
1.2%
Final, 8.9
(b)
COD concentration (mg/L)
600
500
400
300
200
100
0
Final, 512
Initial, 35
Final, 147
Initial, 35
Initial, 35
Final, 15
Reactor I (ORP at -250 mV)
Reactor II (ORP at -150mV)
Reactor III (ORP at -20 mV)

Typical Results

1. initial and final COD (soluble + particulate) was estimated, their difference gives a total COD loss

2. COD consumptions in the corresponding reactions were estimated

3. The amount of COD released as gaseous products was estimated

Parame	Initial sample			
		Reactor I	Reactor II	Reactor III
MLSS (mg/L)	8,906	8,254.0	8,678	8,898
MLVSS (mg/L)	8,194	7,593	7,966	8,129
SCOD (m				
TCOD (m				
VFA (mg as COD/L)	32	46	144	0
pH	7.3	7.5	6.5	7.0
NO_2^--N(mg				
NO_3^--N(mg				
PO_4^{3-}-P(mg/L)	7.6	37.8	32.0	7.9
SO_4^{2-}-S(mg/L)	7.2	3.6	6.3	7.0
Organic carbon (%) in the gas	-	2.03	-	-

Total COD removed in Step (2) and (3) was compared with the total COD loss of the system in Step (1).

COD Balance

Reactor I

COD loss S_{To}-S_{Te} (mg/L)	COD consumption (mg/L)					Unaccounted COD (%)
	Denitrification	Sulfate reduction	Phosphorus release	Gas production	Total COD consumption	
536.32	163	7.2	60.4	266.75	497.4	9.30
431.32	159.22	10.4	70.6	194.18	434.41	-0.72
476.48	166.36	9.6	77.6	213.70	467.26	1.93

Reactor II

COD loss S_{To}-S_{Te} (mg/L)	COD consumption (mg/L)					Unaccounted COD (%)
	(1)	(2)	(3)	(4)	Total COD consumption	
210.54	149.86	1.8	48.8	0	200.46	4.79
215.54	156.99	0.4	45.4	0	202.79	5.91
214.02	164.13	1.2	44	0	209.33	2.19

Expected Sludge Production under Anaerobic and Aerobic Conditions

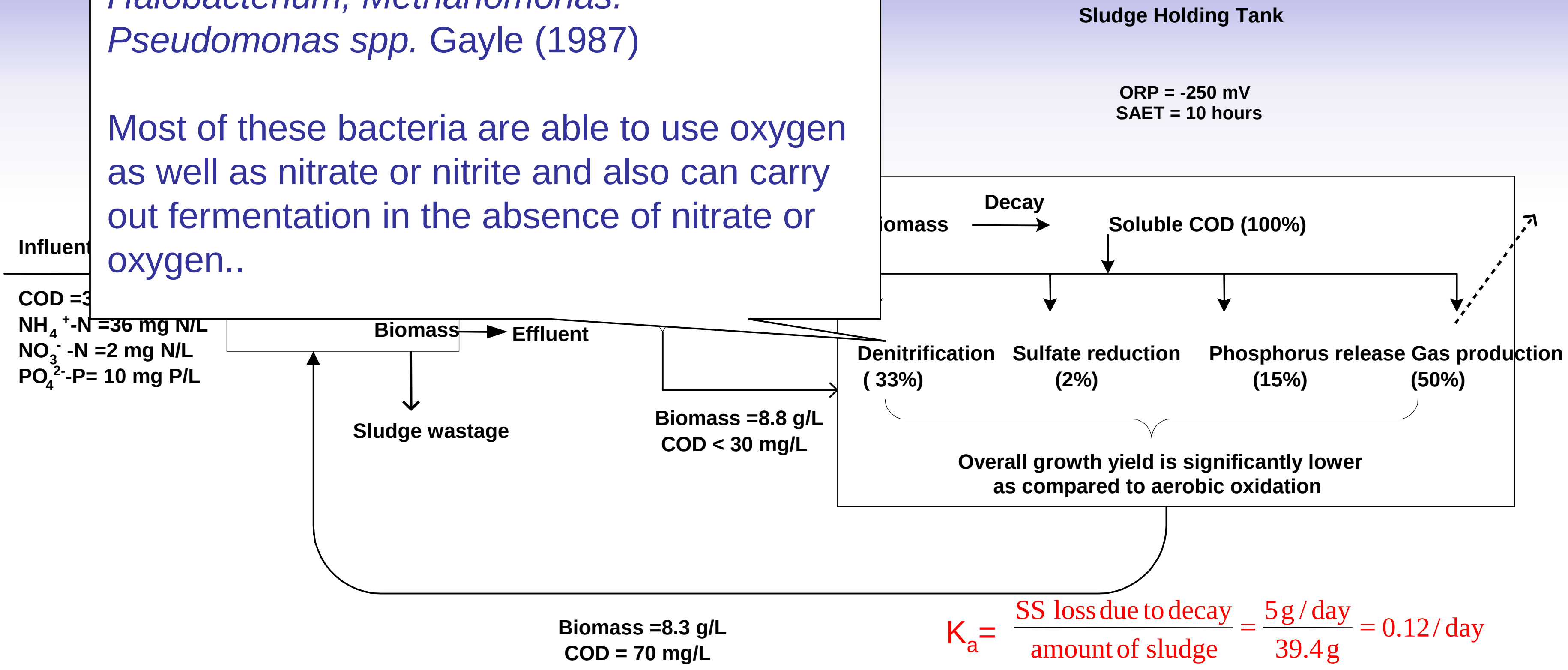
Reaction	Removal of substrate under anaerobic condition			Removal of substrate under aerobic condition	
	COD consumed (mg/L)	Y (g VSS/g COD)	Theoretical sludge production (mg/L)	Y (g VSS/g COD)	Theoretical sludge production (mg/L)
Denitrification	163	0.3	48.9	0.55	251.3
Sulfate reduction	7.2	0.2	1.4		
Phosphorus release	60.4	0.18	10.88		
Gas production	266.8	0.05	13.34		
Total	∑ 497.4		∑ 74.5		∑ 251.3

n of OSA System

Achromobacter, Acinetobacter, Agrobacterium, Alcaligenes, Arthrobacter, Paracocus etc (Payne, 1981)

Halobacterium, Methanomonas. Pseudomonas spp. Gayle (1987)

Most of these bacteria are able to use oxygen as well as nitrate or nitrite and also can carry out fermentation in the absence of nitrate or oxygen..



$$K_a = \frac{\text{SS loss due to decay}}{\text{amount of sludge}} = \frac{5\,g/day}{39.4\,g} = 0.12/day$$

Economic Aspect

		OSA	Typical activated sludge process
Cost increase	Sludge holding tank construction	Q:25,000m3/d,HRT 10h = 10,416 m^3	NO
	Pumping	Additional for sludge pumping	NO
	ORP control unit	Yes	NO
Cost saving	Digester volume	700 m^3/d *15d =10,500 m^3 [1]	1100 m^3 * 15d = 16,500 m^3 [1]
	Sludge Treatment and disposal cost	1.02×10^7 USD/year [2,3] (40USD/ton)	1.6 *10^7 USD/year [2,3]
	Disposal capacity (Landfill)	210 m^3/d	330 m^3/d

Calculation based on 100,000 m^3/d of flow rate for two systems

[1] Metcalf and Eddy, Inc. *Wastewater Engineering: Treatment, Disposal and Reuse* 4th edition, McGraw-Hill. Inc, 2003.

[2] D. G. Christoulas, A. D. Andreadakis, A. Kouzeli-Katsiri, E. Aftias and Mamais, Alternative schemes for the management of the sludge produced at Psyttalis WWTP, *Water Sci. Techol.*, **42**(9), 29-36, 2000.

[3] A. M. Springer, D. V. Guillerom, Feasibility study of sludge lysis and recycle in the activated sludge process, T. Journal May 1996 162-170

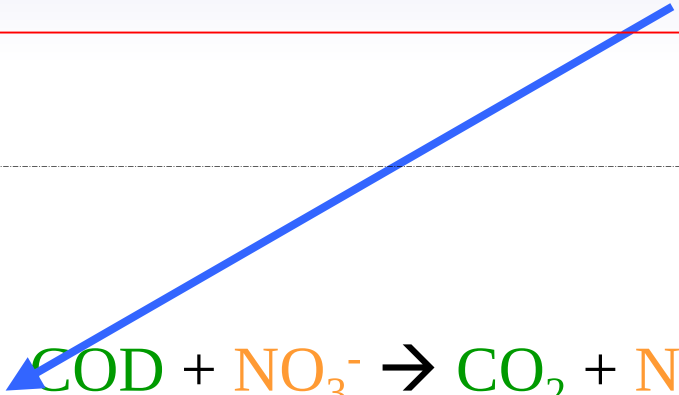
[5] A new solution to Hong Kong Sewage
- A Feasibility Study of Autotrophic Denitrification

- Hong Kong sewage has unique characteristics due to the use of seawater in toilet flushing: sulfate level ~ 500 mg/L, COD ~ 300 mg/L, and chloride ~ 6000 mg/L
- This sulfate level enables efficient sulfidogenic reactions under anaerobic condition, thereby resulting in a very low sludge yield (0.17) and eliminating oxygen demand for carbon oxidation in the subsequent treatment steps.
- If sufficiently produced sulfide, mostly in dissolved form, could be utilized by “Autotrophic Denitrification” as the electron donor, sludge production can be further reduced up to 75% as compared to conventional aerobic-anaerobic processes
- Key point is to shut out carbon source completely from heterotrophic oxidation and denitrification that feature a high sludge yield (0.4-0.5).

REACTION I – Heterotrophic Sulfate Reduction

Y=0.17 $COD + SO_4^{2-} \rightarrow H_2S + HS^-$

Y=0.5 $COD + O_2 \rightarrow CO_2 + H_2O$

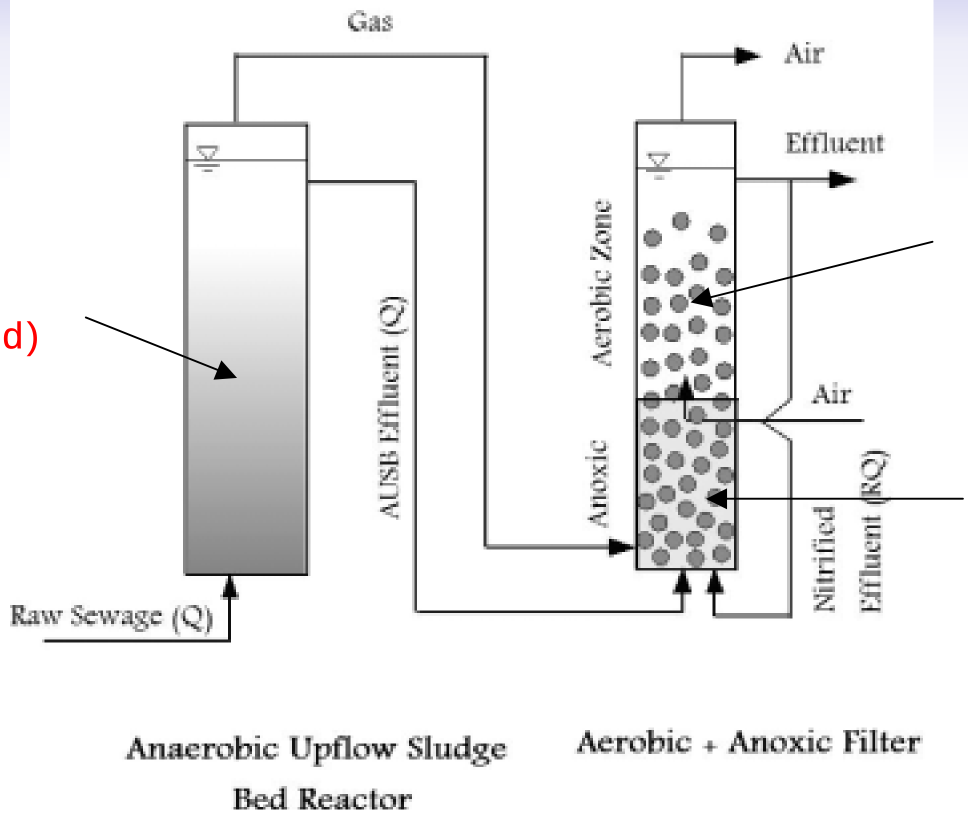


Y=0.4 $COD + NO_3^- \rightarrow CO_2 + N_2$

Y=0.15 $H_2S + HS^- + NO_3^- \rightarrow SO_4^- + N_2$

REACTION II – Autotrophic Denitrification

Proposed New Treatment System for Hong Kong Saline Sewage



COD Removal
(Low sludge yield)

Nitrification
(Low sludge yield)

Autotrophic
denitrification
(Low sludge yield)

Up to 75% excess sludge can be reduced than conventional aerobic-anaerobic processes

Advantages of Proposed Treatment

- Integration of sulfate reduction, autotrophic denitrification, and nitrification to achieve a very low sludge yield
- Efficient COD removal and complete nitrogen removal are possible.
- Neither chemical nor physical forces are needed, oxygen demand is also reduced greatly. Thus, a very low operation cost can be expected.

Objective of this study

- To confirm efficiency of COD removal through sulfate reduction (Phase I)
- To study efficiency of autotrophic denitrification (AD) and its affecting factors (Phase I)
- To investigate performance of the integrated system for nitrogen and COD removal and excess sludge reduction (Phase II)
- To identify SRB and ADB bacteria (Phase II)
- Pilot study of the proposed system at sewage treatment works (Phase III)

Reactor I

Phase I Results

Reactor I (SR Bioreactor)

- Diameter = 10 cm, Height = 40 cm
- Volume = 3L
- Feeding synthetic sewage
  (TOC ~ 100mg/L, SO_4^- ~ 500mg/L)

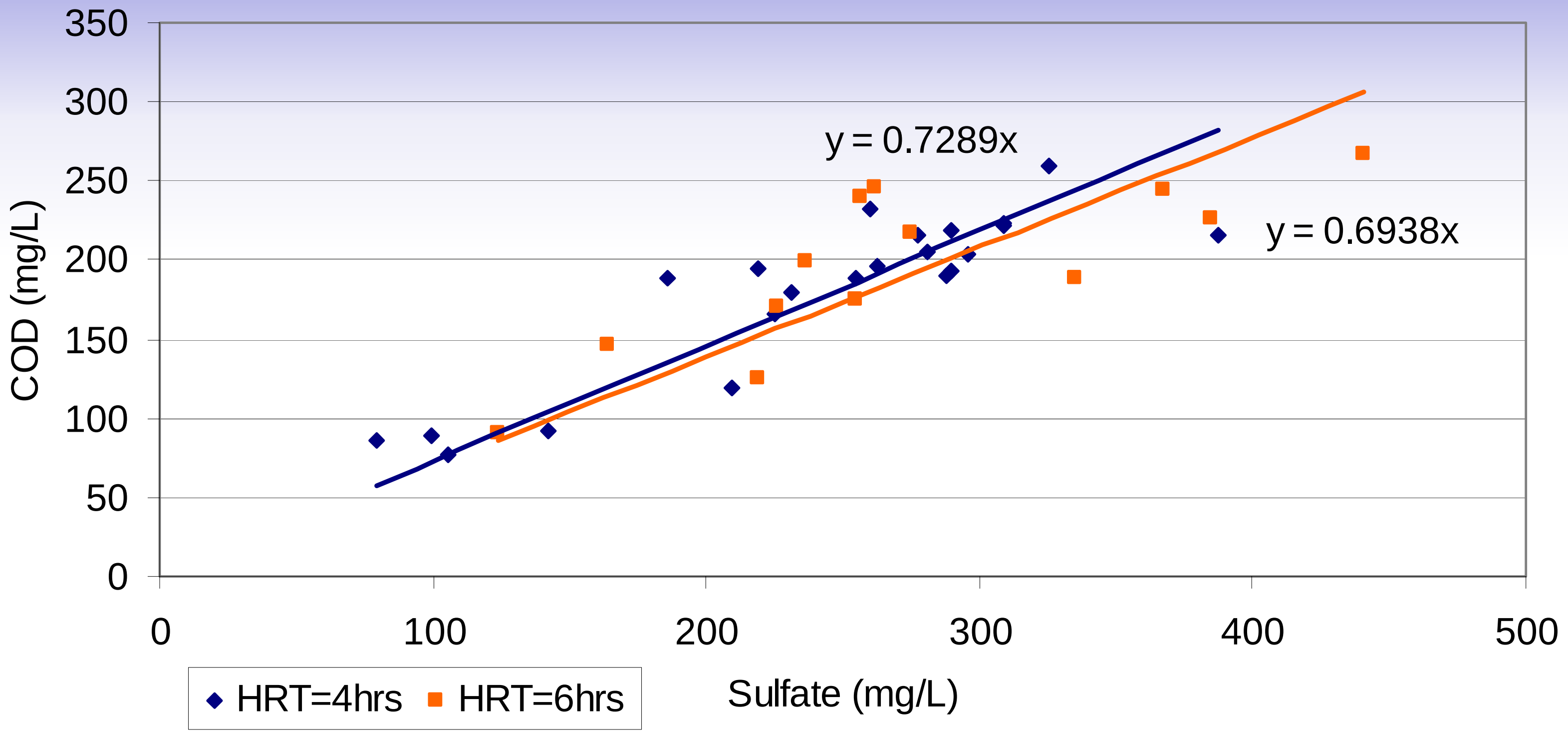
- Reactor II (Submerged AD Bio-filter)
  - Diameter = 10 cm, Height = 30 cm
  - Volume ~ 2.15 L
  - Feeding effluent from reactor I with external nitrate source (30 N-mg/L)

Reactor II

Summary of Reactor I (SRB) Performance

Parameters	**Hydraulic Retention Time**	
	4 hrs	**6 hrs**
Influent Flow Rate (L/hr)	0.8	0.53
TOC (mg/L)		
Influent (Average)	95	90
Effluent	16.3 ± 4.2	14.6 ± 2.7
TOC Removal %	**82.4 ± 0.1**	**86.9 ± 5.1**
Sulfate (mg/L)		
Influent	480.4 ± 116.7	660.6 ± 166.1
Effluent	220.3 ± 110.2	382.2 ± 111.9
Sulfate Removal	260.1 ± 113.4	278.4 ± 139.0
Average organic loading rate		
kg TOC/m^3-day	0.57	0.35
Sludge Yield (g VSS / g COD)	**0.17**	**0.16**

COD / SO_4^{2-} Ratio in Reactor I



- Theoretical COD / SO_4^{2-} ratio for sulfidogenic reaction= **0.67**
- Experimental COD / SO_4^{2-} Ratio ~ **0.65 – 0.93**
- Majority of COD was utilized by sulfate reducers

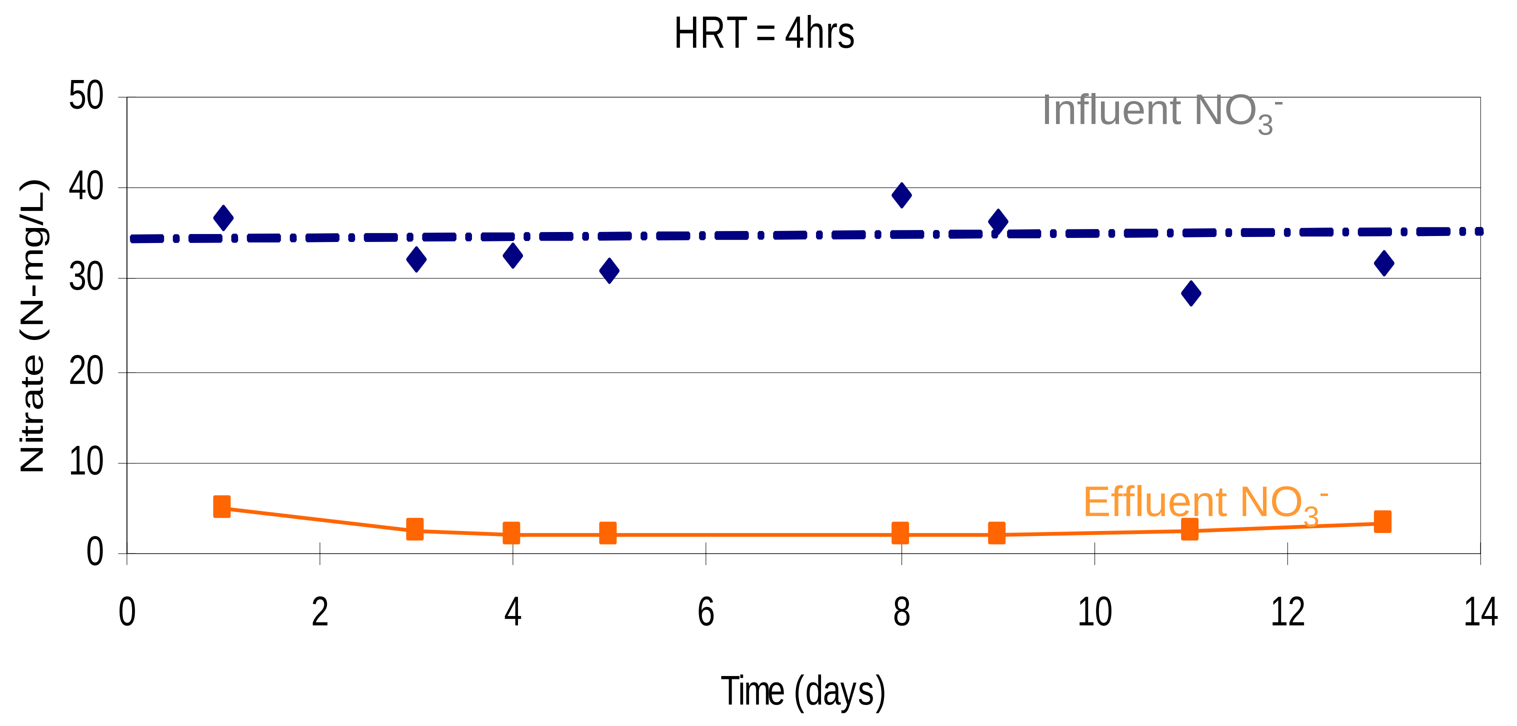
Sulfur Balance in Reactor I

Measured Sulfur Source

- ***Influent***
  - Sulfate ~ **154.2 mg S/L**
- ***Effluent***
  - Sulfate ~ **64.2 mg S/L**
  - Total dissolved sulfide ~ **72.5 mg S/L**
- Sulfate Reduced = 90 mg S/L
- About 80% of the sulfide produced is in the dissolved form

- The remaining sulfur may include:
  - ☐ hydrogen sulfide gas
  - ☐ biomass sulfur
  - ☐ Metal sulfide

Performance of Reactor II (SADB)



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Summary of SADB Performance

	Influent	*Effluent*	*Efficiency*
NO_3^- (N-mg/L)	33.8	1.3	96%
SO_4^{2-} (mg/L)	259.7	373.2	
SO_4^{2-} (mg S/L)	86.6	124.4	
Dissolved Sulfide (mg S /L)	72.5	-	

Sufficient NO_3^- removal in HRT = 4 hrs

- TOC removal < 5mg/L
- Theoretical Ratio: SO_4^{2-} / NO_3^- = **1.92 – 2.51** mg S/ mg N
- Experimental Ratio:SO_4^{2-} / NO_3^- = **2.1** ± **1.19** mg S / mg N

Acknowledgement

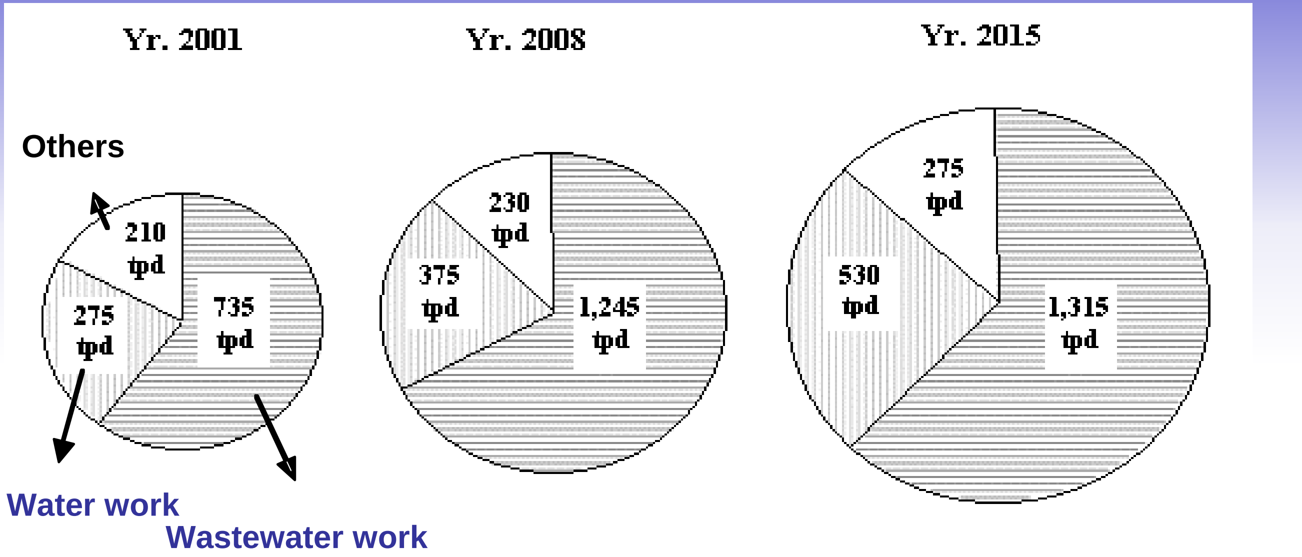
- Following organizations should be acknowledged for financially supporting our work:

  Hong Kong Research Grants Council
  HKUST
  Vivendi Water

The end

Thank you very much for your attention and patience.

Sludge Production and Landfill Capacity Example of Hong Kong



Projected daily sludge production from water and wastewater treatment works in Hong Kong

Sludge production and landfill assimilative capacity in Hong Kong

Year	1991	2001	2008	2015
Sludge quantity (ton/day)	510	1200	1850	2120
Landfill capacity (ton/day)	1690	1500	1800	2050