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Prototype Study of Biofilm Processes with Mobile Carriers for Sewage Treatment

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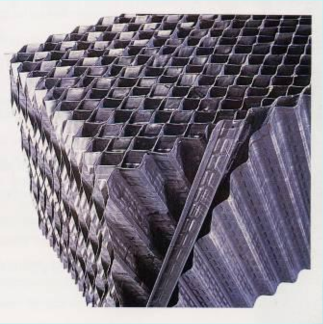
Introduction – Biofilm Processes

- Biofilm Processes (Attached Growth)
  - With Fixed-bed Media
    - Rotating Biological Contactor (RBC)
    - Trickling Filter
    - Submerged Aerated Filter (SAF)
    - Biological Aerated Filter (BAF)
  - With Moving-bed Media
    - Moving Bed Bioreactor (MBBR)
    - Integrated Fixed Film Activated Sludge (IFAS)

Introduction – Biofilm Media

- Fixed-bed Media





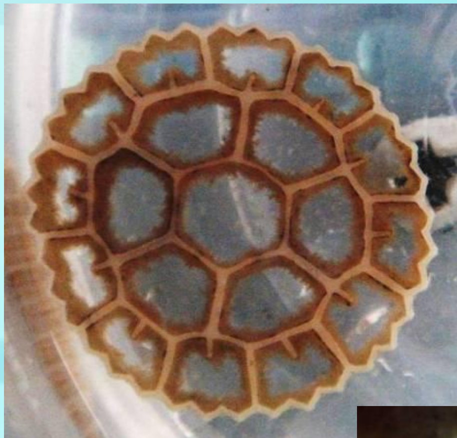


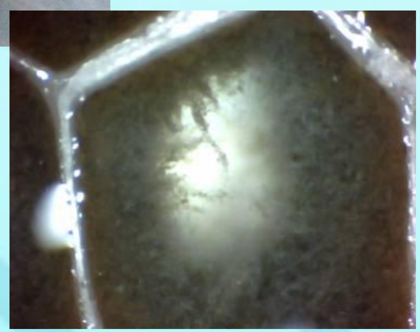


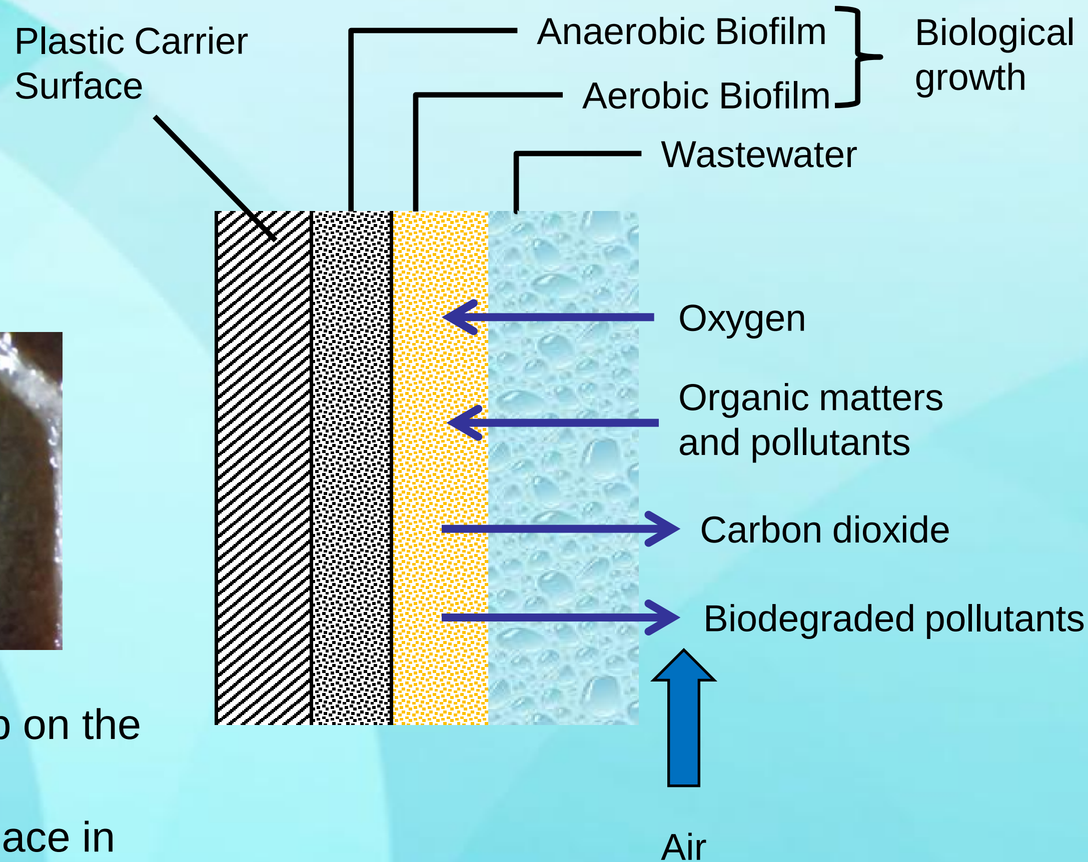
- Moving-bed Media




Introduction – Biofilm Processes







- Microorganisms grow and develop on the surface of MBBR carrier (biofilm)
- Decomposition of organics take place in biofilm
- As biofilm grows thicker, it will slough off from the carrier and settled as sludge

Introduction – Prototype Study

- CEPT effluent from the SCISTW needs further treatment under the HATS 2B to meet the future WQO

- In view of the space constraints in SCISTW, DSD has commissioned HKPC to evaluate the applicability and performance of biofilm processes with mobile carriers on treating the CEPT effluent

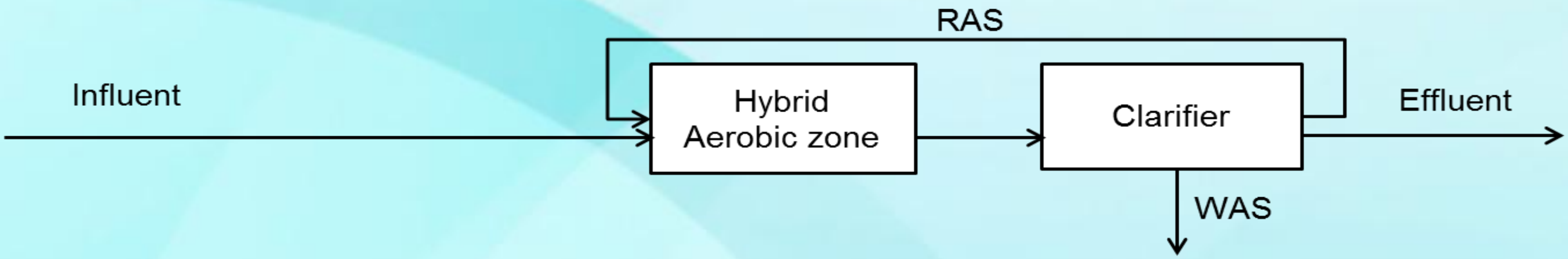
- The prototype reactors were housed in a 20-ft container in SCISTW

- The study was conducted between 12 Oct 2010 and 28 Jun 2012

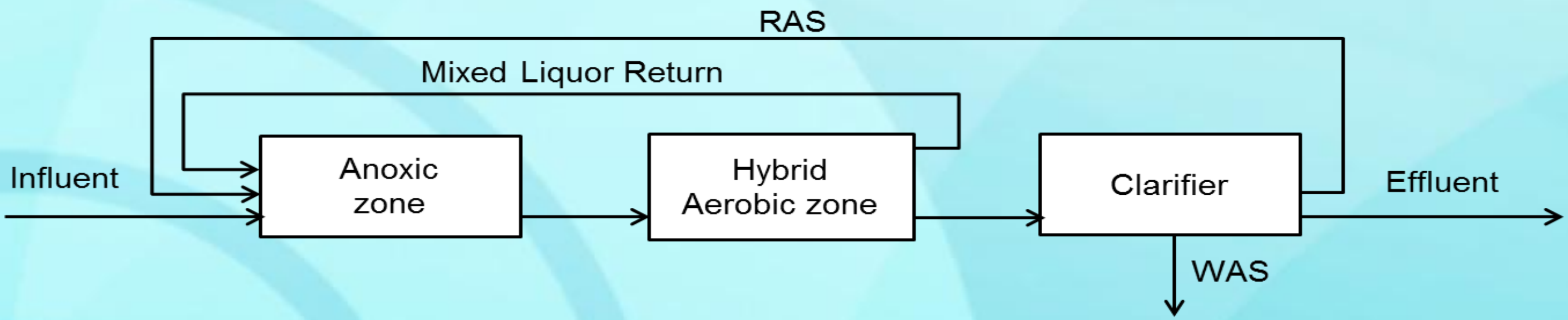


Schematics of Biofilm Reactors

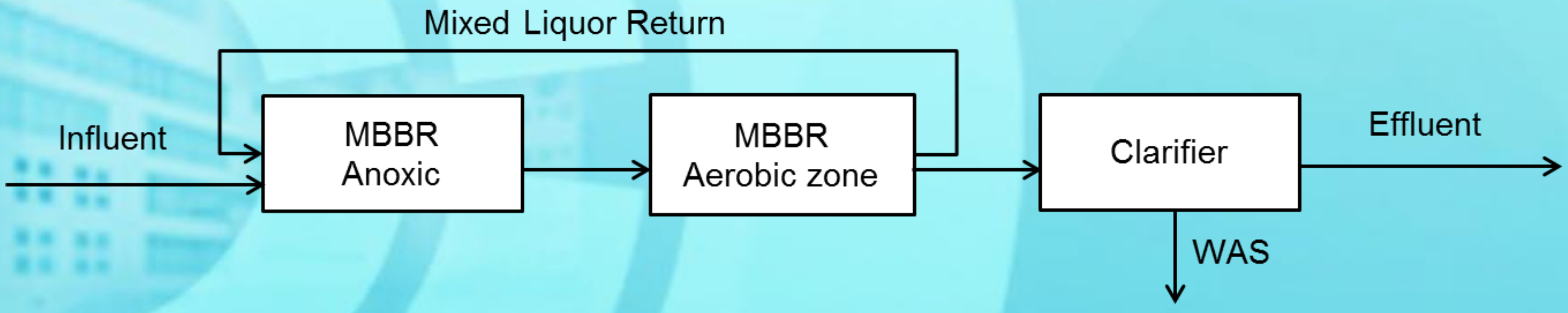
- Fully-Aerated (**FA**) System – hybrid system without denitrification



- Integrated Fixed Film Activated Sludge (**IFAS**) – hybrid system with denitrification



- Moving Bed Biofilm Reactor (**MBBR**) System – pure attached-growth system



Objectives of Prototype Study

- To assess the effectiveness of using biofilm reactors to treat the CEPT effluent and raw sewage

- To operate the prototypes at stressed conditions so as to determine the maximum loading/shortest HRT that can be accepted by the biofilm reactors to meet generic effluent criteria:
    - $BOD_5 \leq 20$ mg/L
    - TSS ≤ 30 mg/L
    - Ammonia-nitrogen ≤ 5 mg/L @18°C

- To assess the denitrification performance of the biofilm reactors (based on TN ≤ 20 mg/L)

- To estimate the sizes of the biofilm reactors for SCISTW for illustration

Introduction

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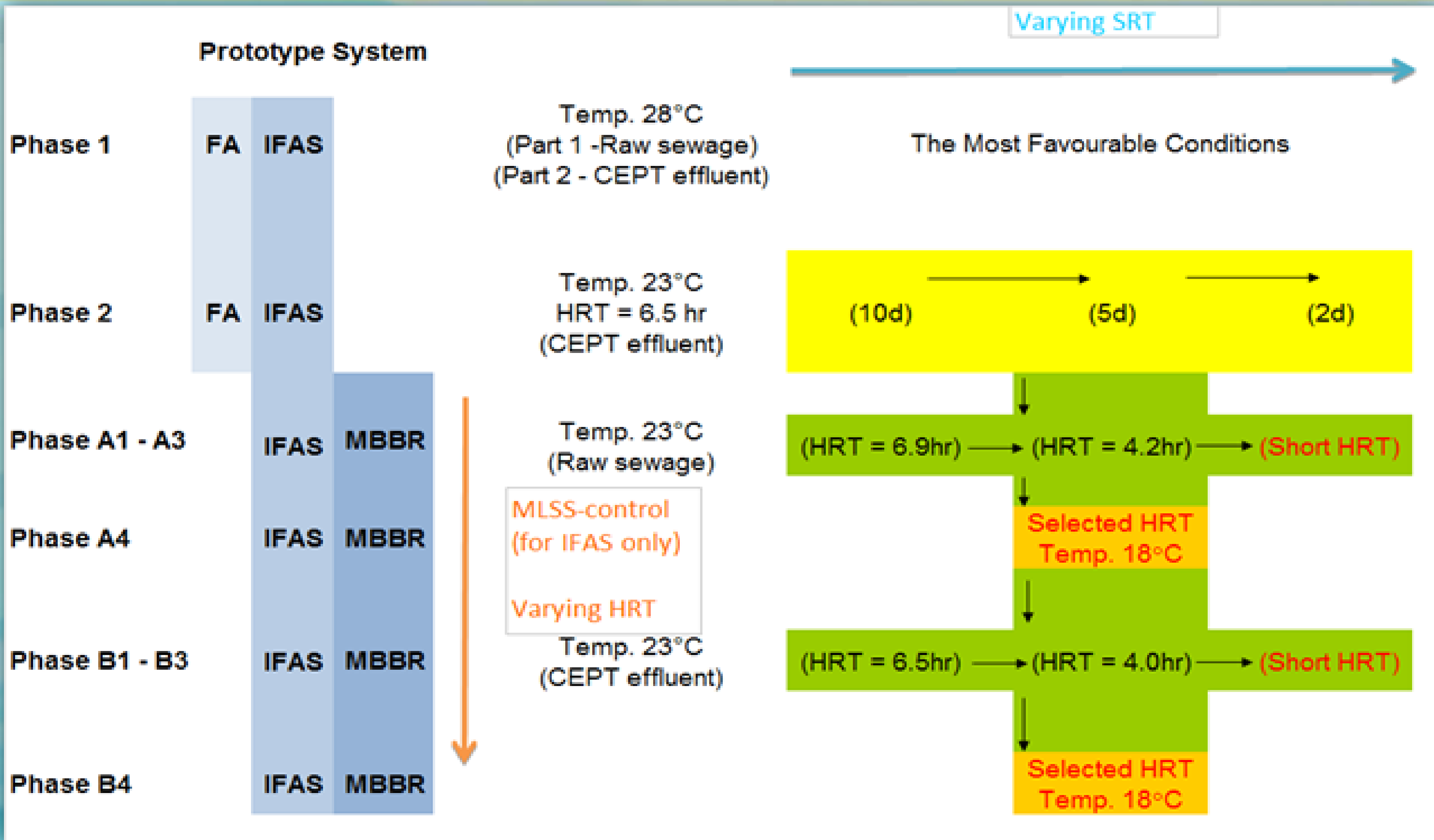
System Parameters of FA, IFAS and MBBR

	FA	IFAS	MBBR
Volume of tank	150 L	150 L	150 L
Volume of anoxic zone	N/A	45 L (30%)	60 L (40%)
Volume of aerobic zone	150 L	105 L (70%)	90 L (60%)
Volume of carriers in anoxic zone	N/A	N/A	30 L (50%)
Volume of carriers in aerobic zone	90 L (60%)	63 L (60%)	59 L (65%)
Mobile carriers	AnoxKaldnes K3		
Specific biofilm surface area (in bulk)	500 m^2/m^3		
Biofilm surface area used in anoxic zone	N/A	N/A	15 m^2
Biofilm surface area used in aerobic zone	45.0 m^2	31.5 m^2	29.5 m^2
Range of Flow rate	400–1,700 L/day		
DO setting in aerobic zone	3 – 4 mg/L		

Study Programme



Comparison between FA and IFAS

Comparison between FA and IFAS

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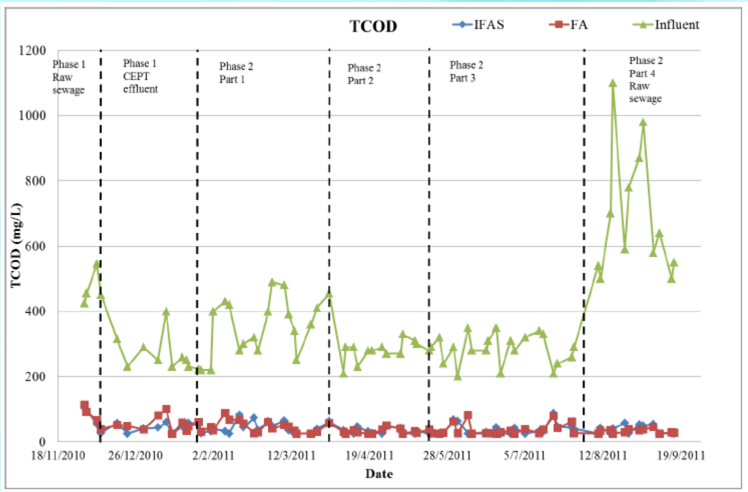
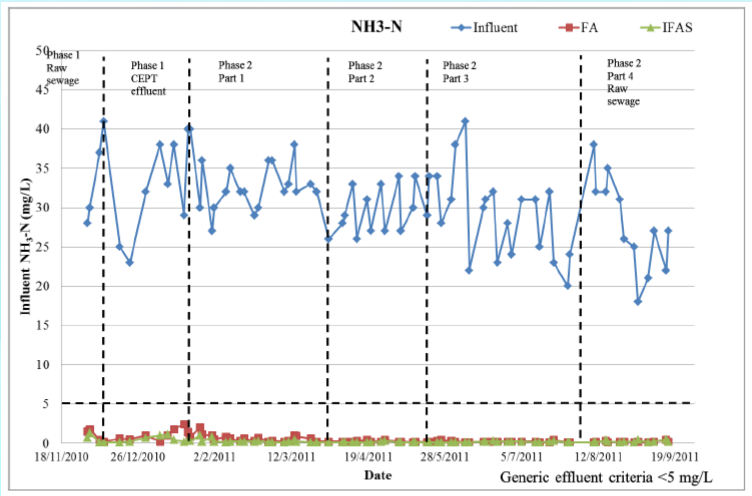
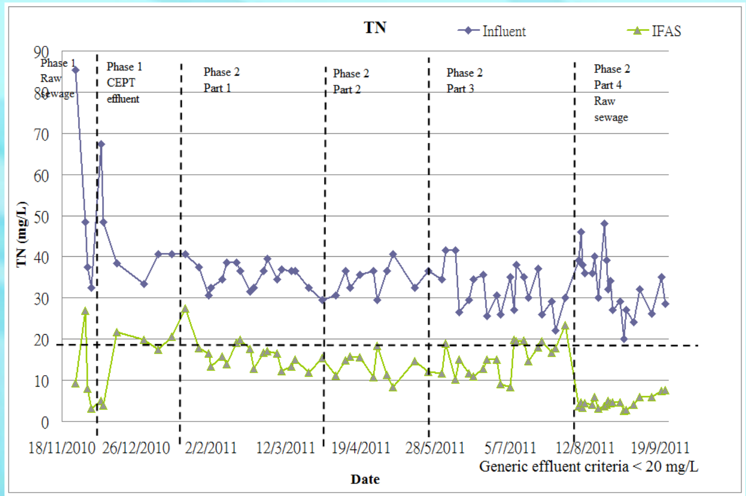
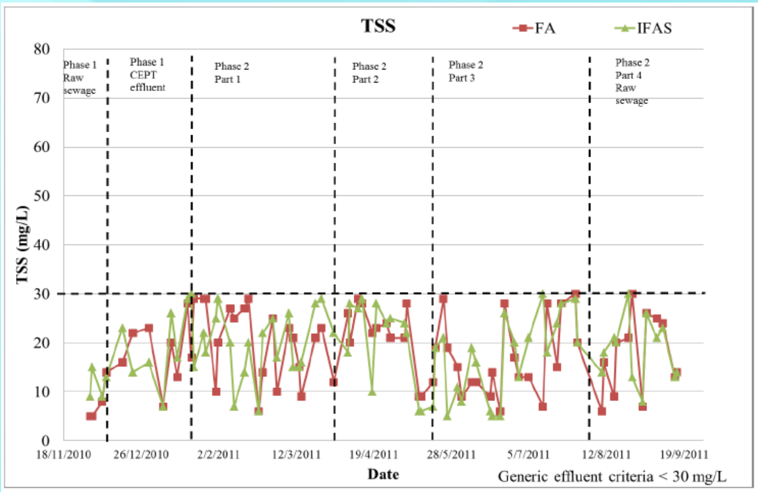
- At moderate HRT (~6.5 hr), FA and IFAS could fully meet the effluent criteria of TCOD, TSS and NH_3-N when treating both raw sewage and CEPT effluent at 23°C.

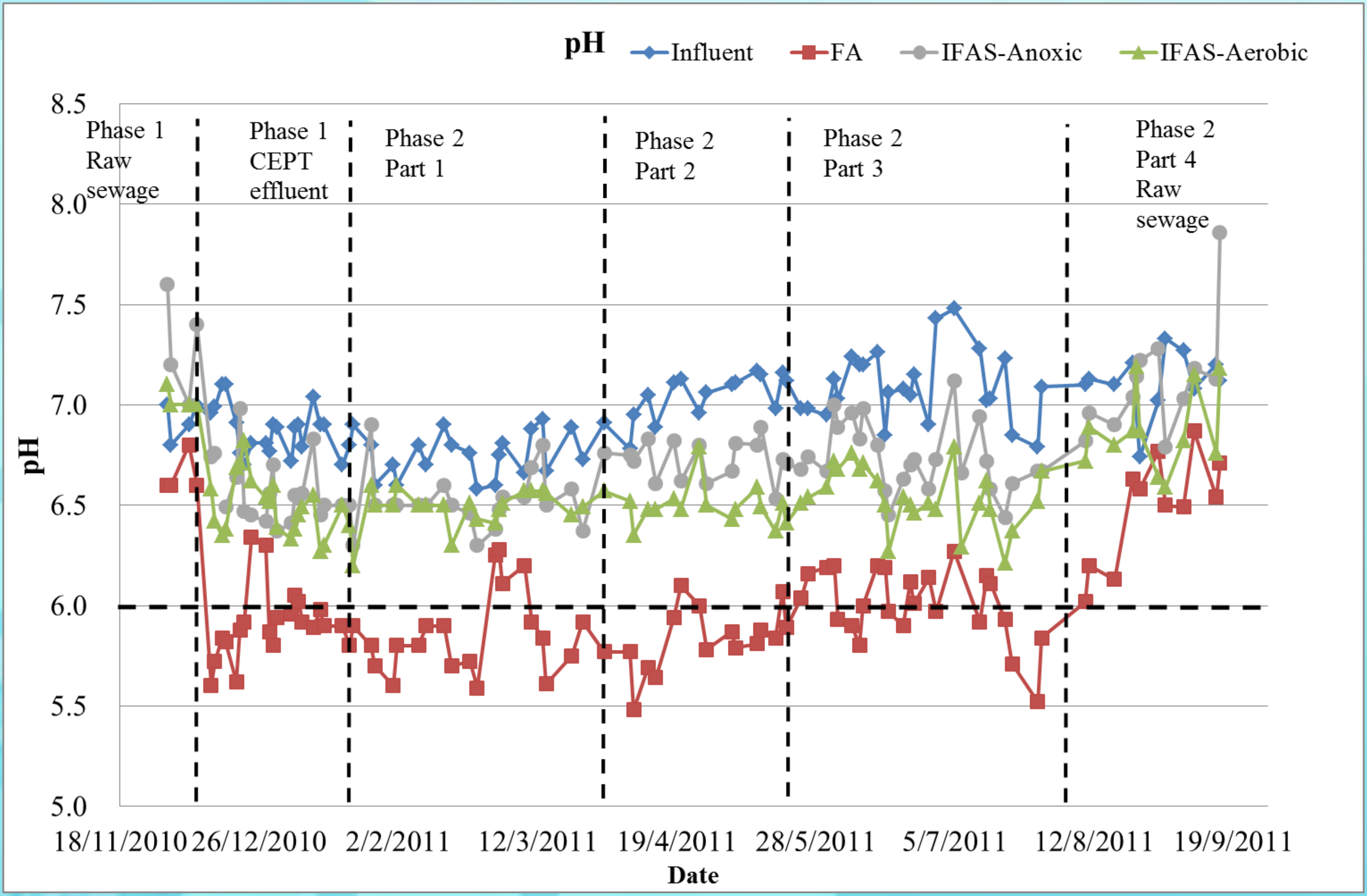








Comparison between FA and IFAS



Comparison between FA and IFAS

1) Hybrid **FA** system without pre-denitrification suffered from pH drop problem after nitrification when treating CEPT effluent

2) Hybrid system with pre-denitrification (IFAS) has the merits of TN removal and supplementation of alkalinity consumption and oxygen requirement

3) Limitation of **IFAS** – when the reactor MLSS is further reduced, *pre-denitrification performance may deteriorate*.

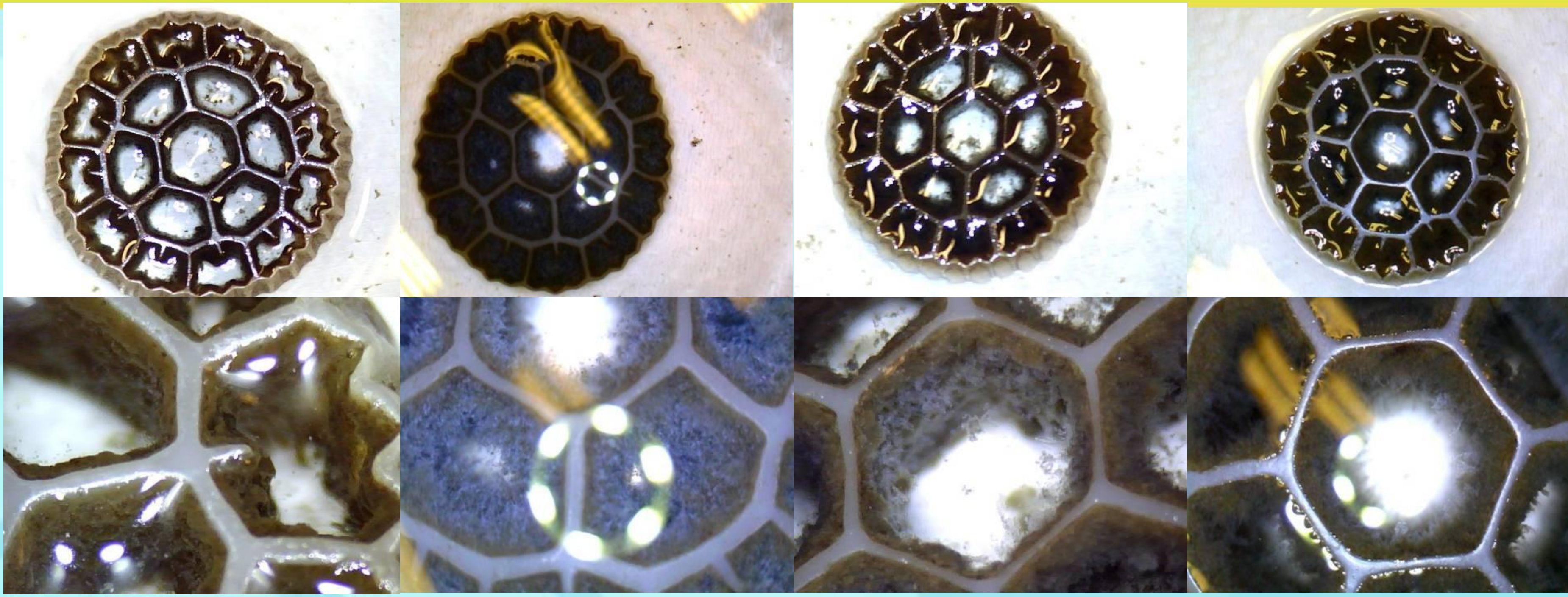
Comparison between Treating Raw Sewage and CEPT Effluent

Shorter Min HRT in CEPT Effluent at 23°C and 18°C

- Minimum HRT required for MBBR and IFAS to treat CEPT effluent were impressively short

Prototype System	Operating Temp.	Min. HRT (hr)			% Reduction in Min. HRT
		Raw Sewage		**CEPT Effluent**	
IFAS	23°C	4.2	→	2.4	43%
	18°C	5.1 – 5.6	→	3.1 – 3.2	39 – 42%
MBBR	23°C	6.2	→	3.8	39%
	18°C	7.2 – 7.8	→	4.5 – 4.9	38%

Biomass Overgrowth under High Loading Rates of Raw Sewage



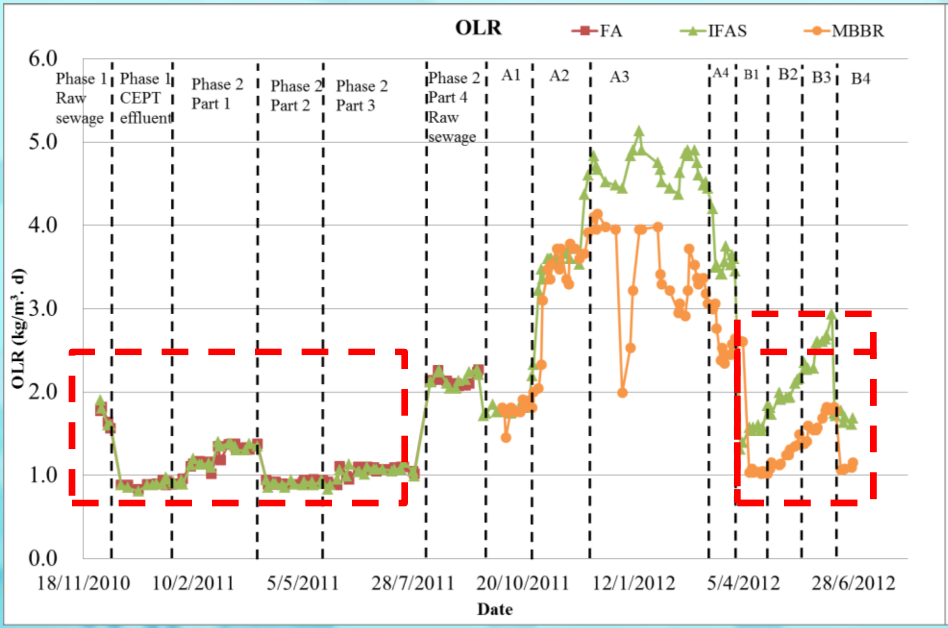
Normal Condition | *Biomass Overgrowth* | *Normal Condition* | *Biomass Overgrowth*

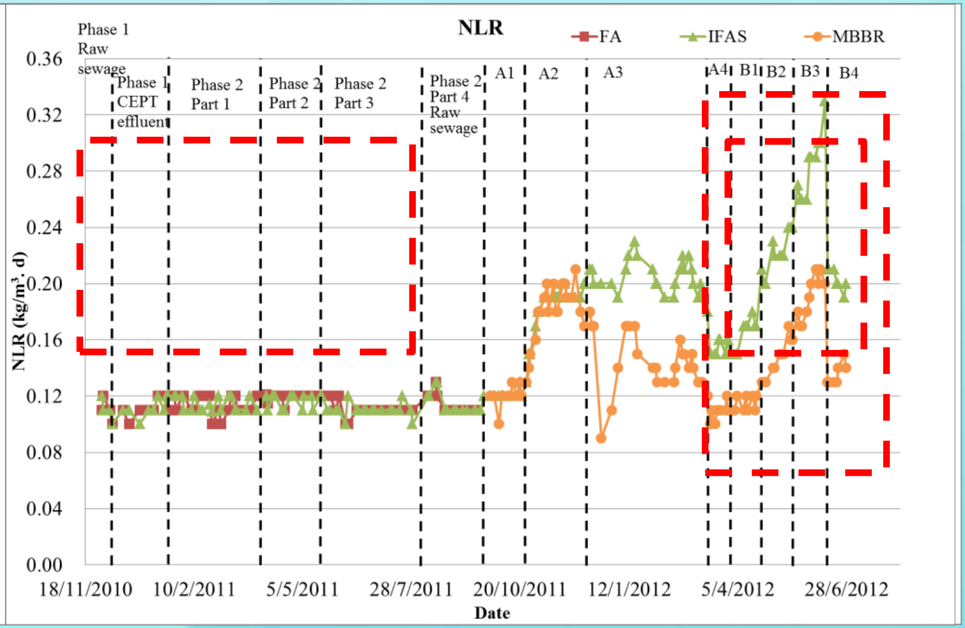
MBBR | **IFAS**

- Flourishing growth and thick layer of heterotrophic biomass
- Hinder oxygen from penetrating into the biofilm of nitrifiers
- Suppressed growth and activities of nitrifiers
- Poor ammonia removal performance
- Long restoration period

Lower Organic Content in CEPT Effluent Favouring Ammonia-N Removal

- CEPT effluent had lower COD and BOD_5 contents but comparable levels of NH_3-N and TKN as raw sewage
- When treating CEPT effluent, higher NLR could be achieved as corresponding OLR was not as high as on treating raw sewage.
- CEPT effluent was more favourable to higher NLR and shorter HRT.





TN Removal of IFAS and MBBR on treating CEPT Effluent

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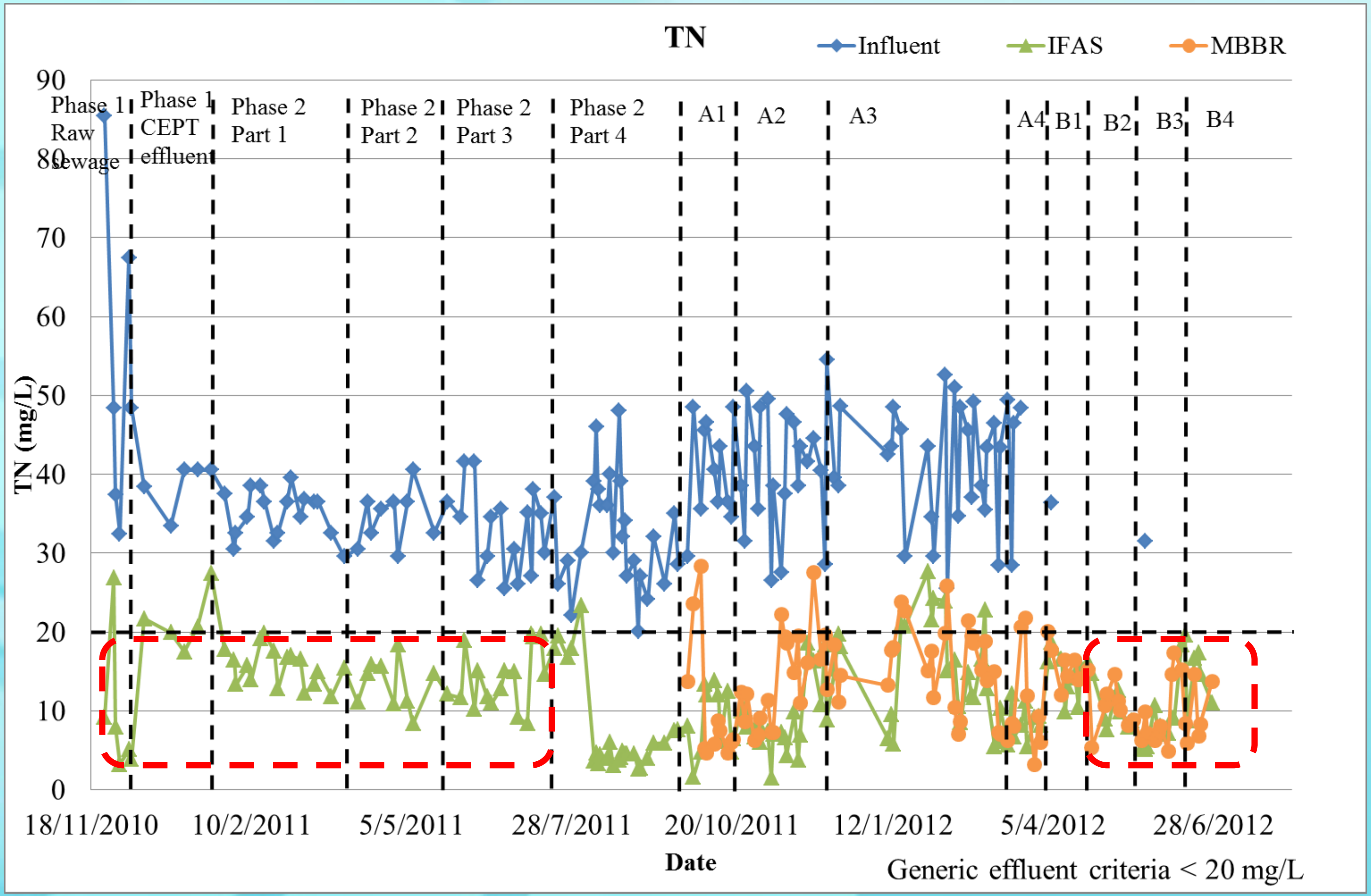
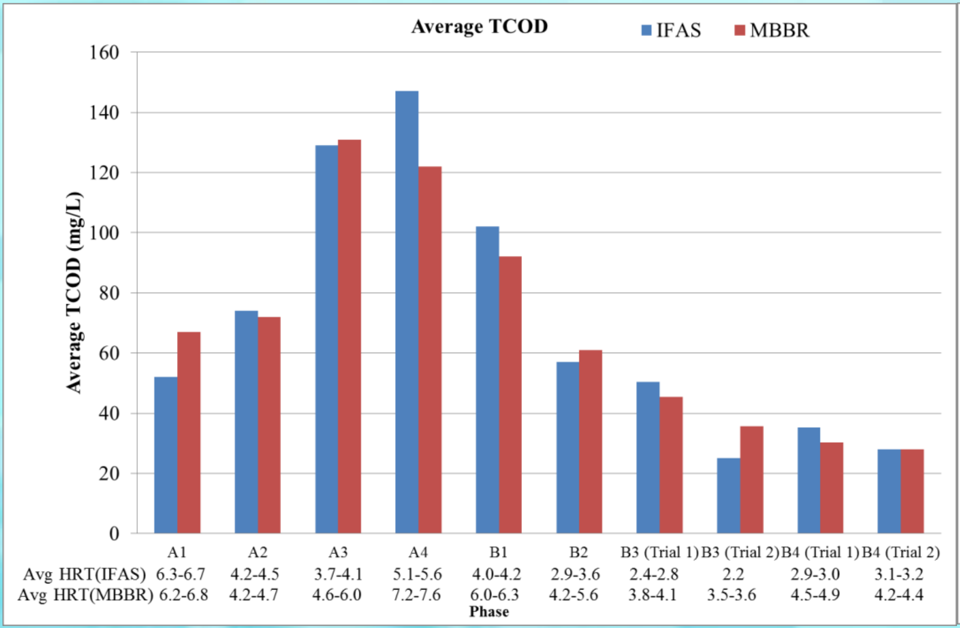
- Effluent TN of IFAS and MBBR on treating CEPT effluent could comply with the effluent criteria of TN ≤ 20 mg/L, but not so good as treating raw sewage because of less carbon source to facilitate denitrification.

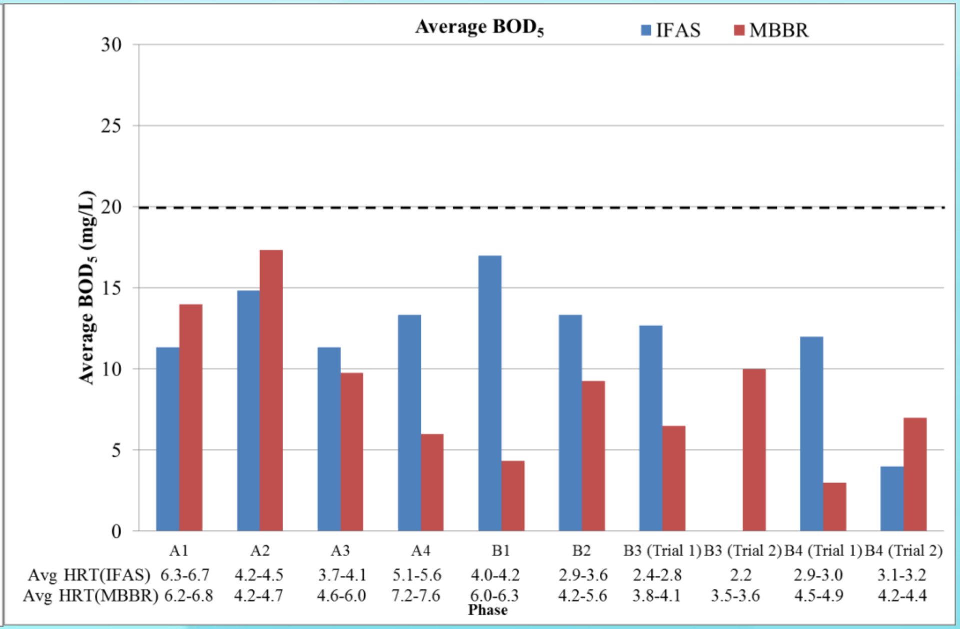


Comparison between IFAS and MBBR

COD and BOD_5 Removal

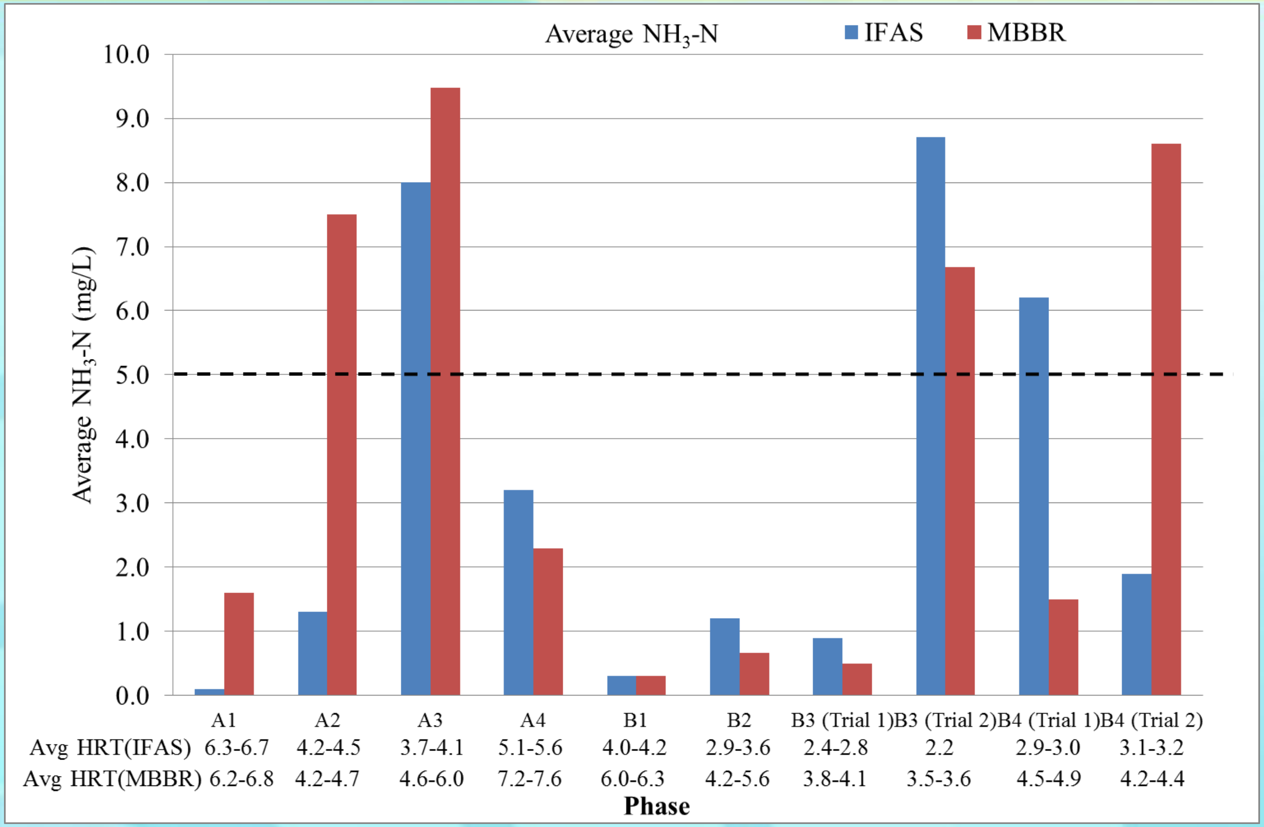
- Comparable and satisfactory treatment performance in COD and BOD_5 removal
- MBBR showed slightly better removal on COD and BOD_5
- Both systems started deteriorating under very high loading conditions
- It took time for biomass acclimatization





Notes: The generic effluent criteria of $BOD_5 \leq 20$ mg/L.

NH_3-N Removal



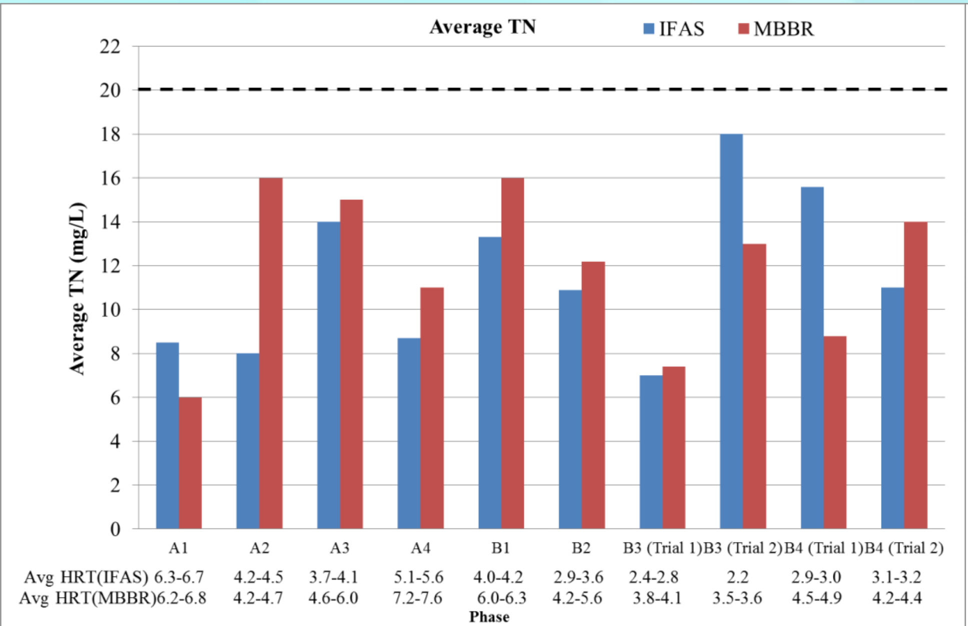
Notes: The generic effluent criteria of NH_3-N ≤ 5mg/L.

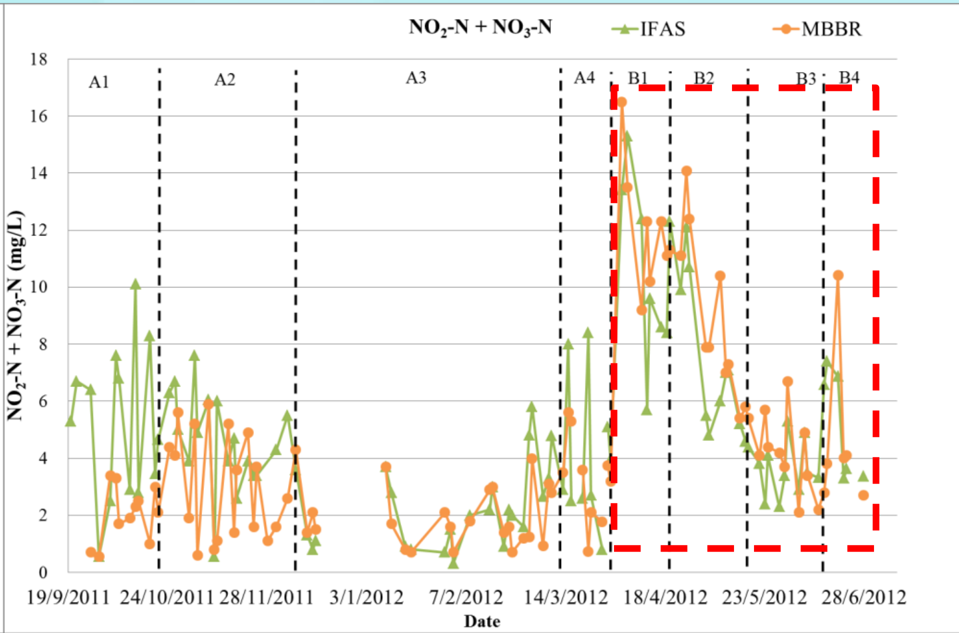
- NH_3-N removal was the limiting factor in treatment performance
- Low effluent NH_3-N could be achieved under favourable operating condition
- NH_3-N removal was impaired by biomass overgrowth or under stressed condition

- **To facilitate higher NLR and shorter HRT**
  - ➢ Control OLR within acceptable level to avoid biomass overgrowth
  - ➢ Separate nitrification from carbonaceous removal process (only applicable to MBBR)

TN Removal and Effluent NO_2-N + NO_3-N

- Both IFAS and MBBR showed satisfactory denitrification performance. Effluent TN of both systems ≤ 20mg/L so TN was *not a limiting factor*
- Effluent NO_2-N + NO_3-N of both systems was *higher* on treating CEPT effluent, showing better denitrification when treating raw sewage.

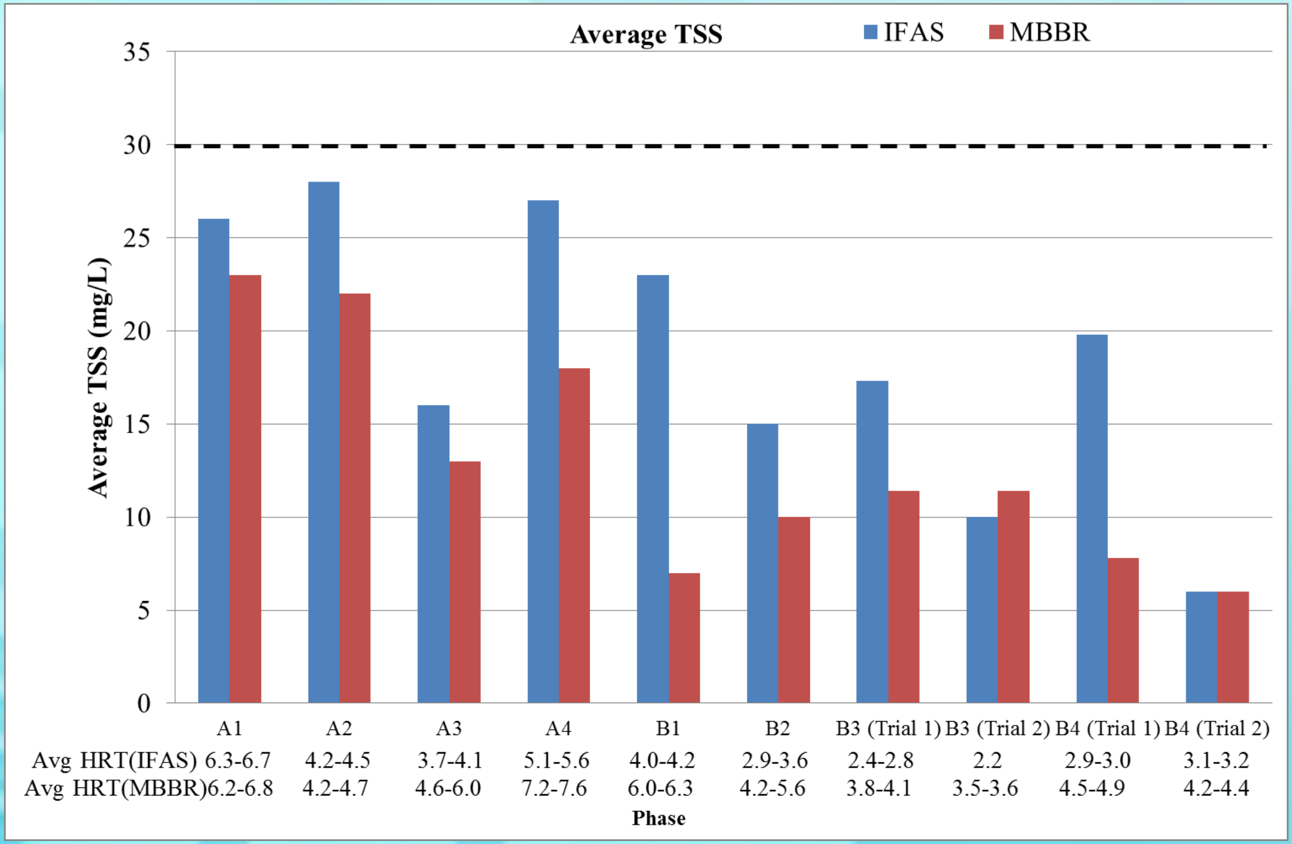




Notes: The generic effluent criteria of TN ≤ 20 mg/L.

Effluent SS

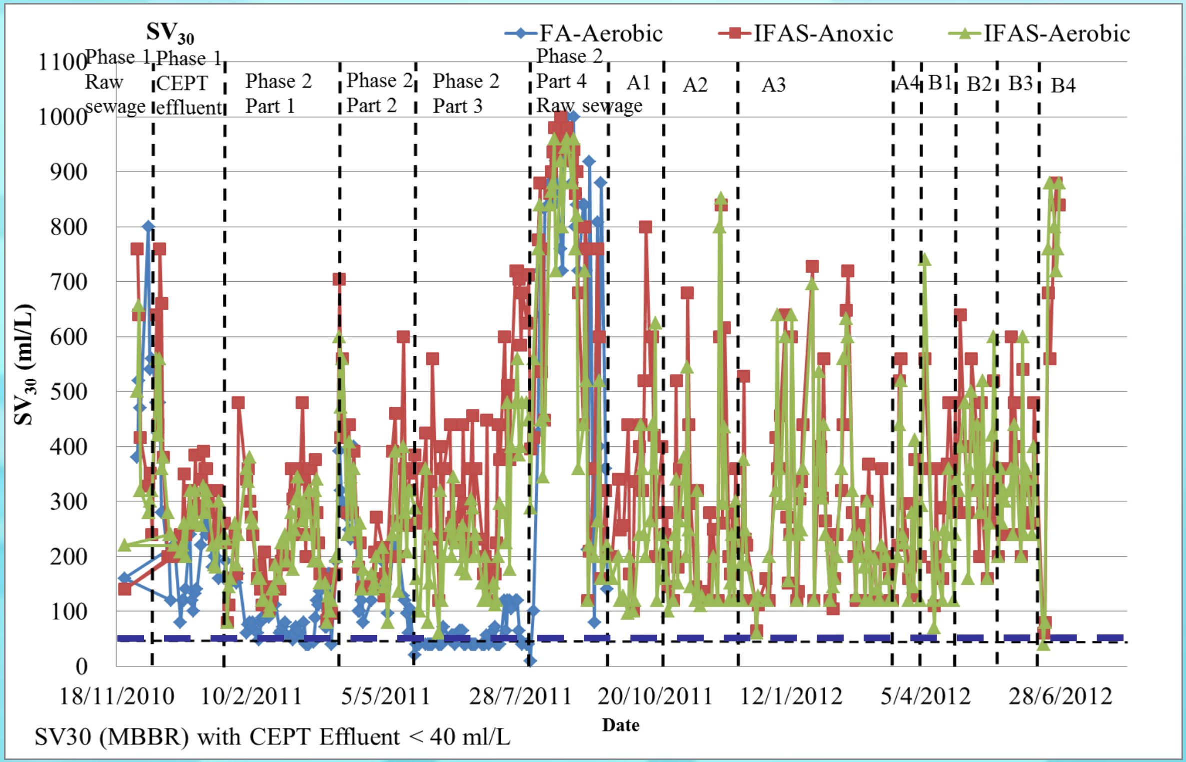
- **Effluent TSS of MBBR** was *better than* IFAS on treating either raw sewage or CEPT effluent.
- **MBBR** had more flexibility on final clarification due to much lower solid loading to the final clarifiers and no sludge return

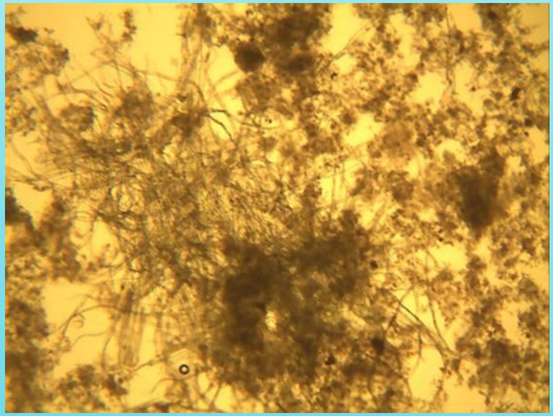


Notes: The generic effluent criteria of TSS ≤ 30mg/L.

MLSS and Sludge Settling Properties

- While SV_{30} of MBBR maintained at < 40 ml/L when treating CEPT effluent, SV_{30} of FA and IFAS fluctuated between 100 – 1000 ml/L.
- IFAS suffered the occurrence of filamentous bacteria (**sludge bulking**) under high loading conditions.
- **Final clarification for IFAS** is *relatively difficult* and requires longer retention time.





Minimum HRT of IFAS and MBBR

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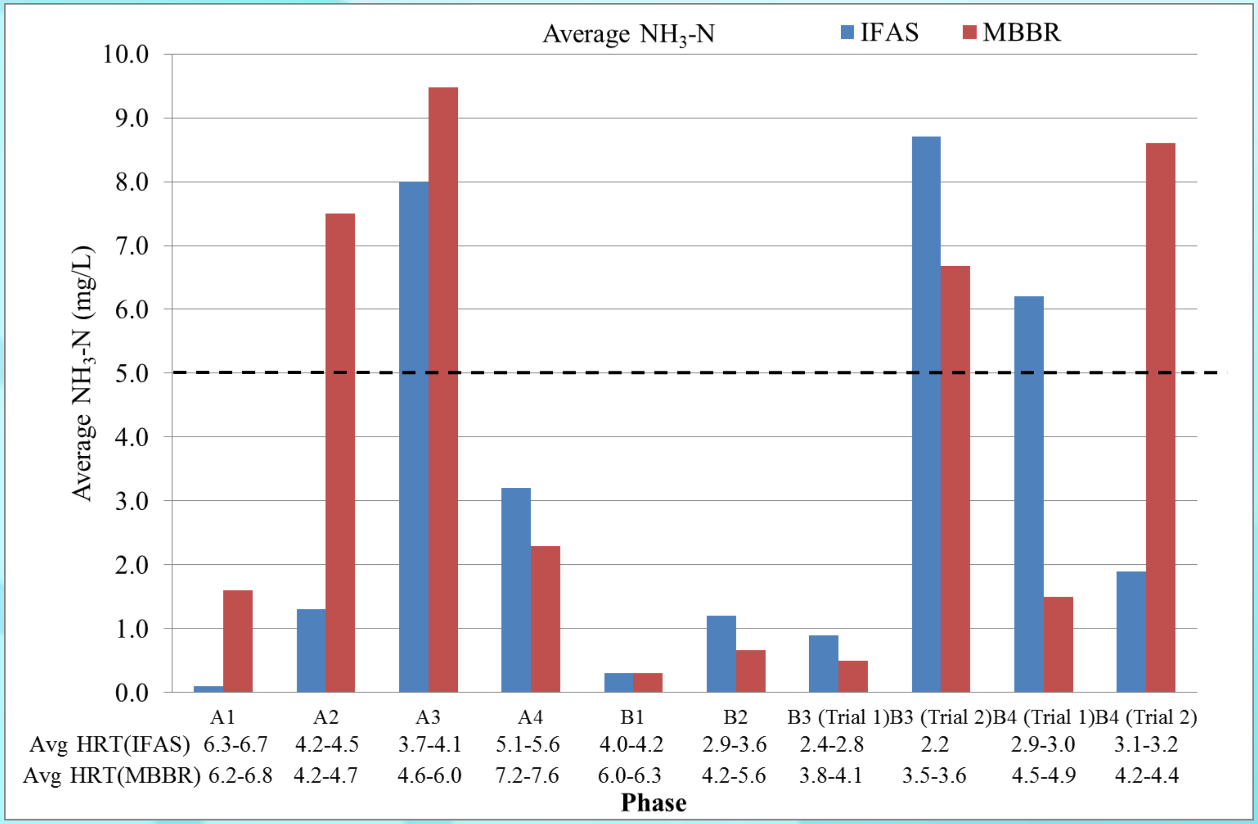
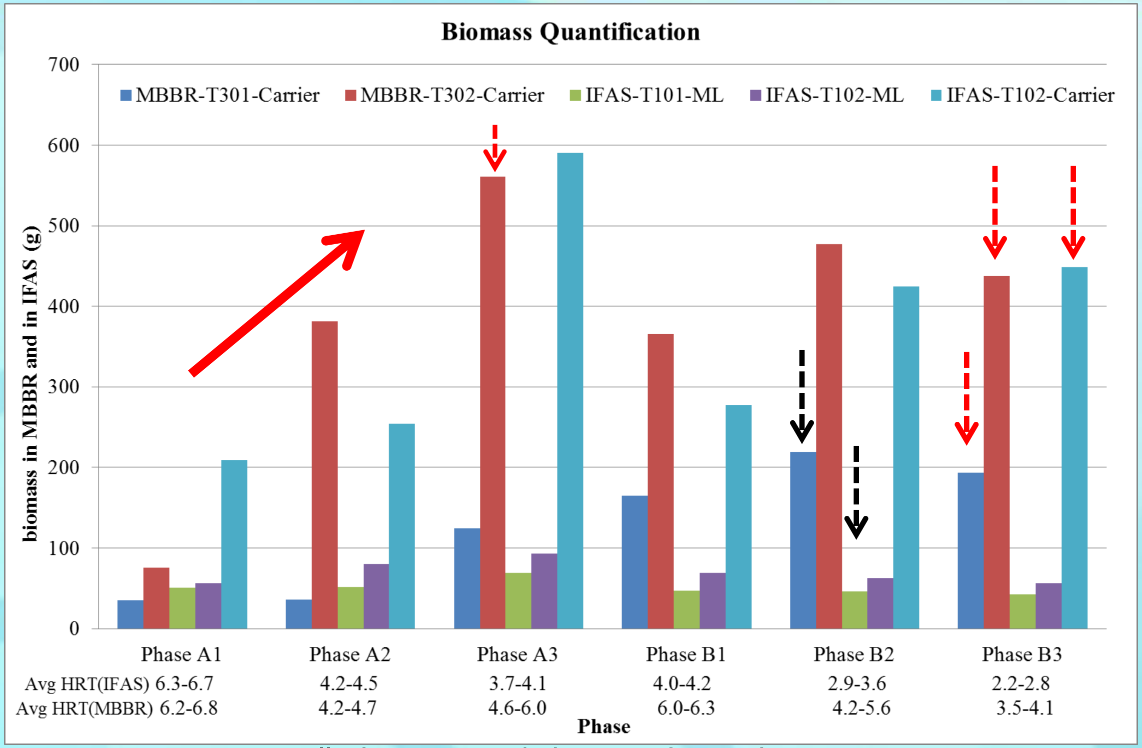
Minimum HRT achieved by IFAS and MBBR were governed by NH_3-N removal efficiency



Prototype System	**MBBR**		**IFAS**	
Operating Temp. (℃)	23	18	23	18
Raw Sewage	6.2	7.2 – 7.8	4.2	5.1 – 5.6
CEPT Effluent	3.8	4.5 – 4.9	2.4	3.1 – 3.2

Biomass in IFAS and MBBR



Notes: MLSS controlled at 900 mg/L in IFAS from Phase 2 Part 4.

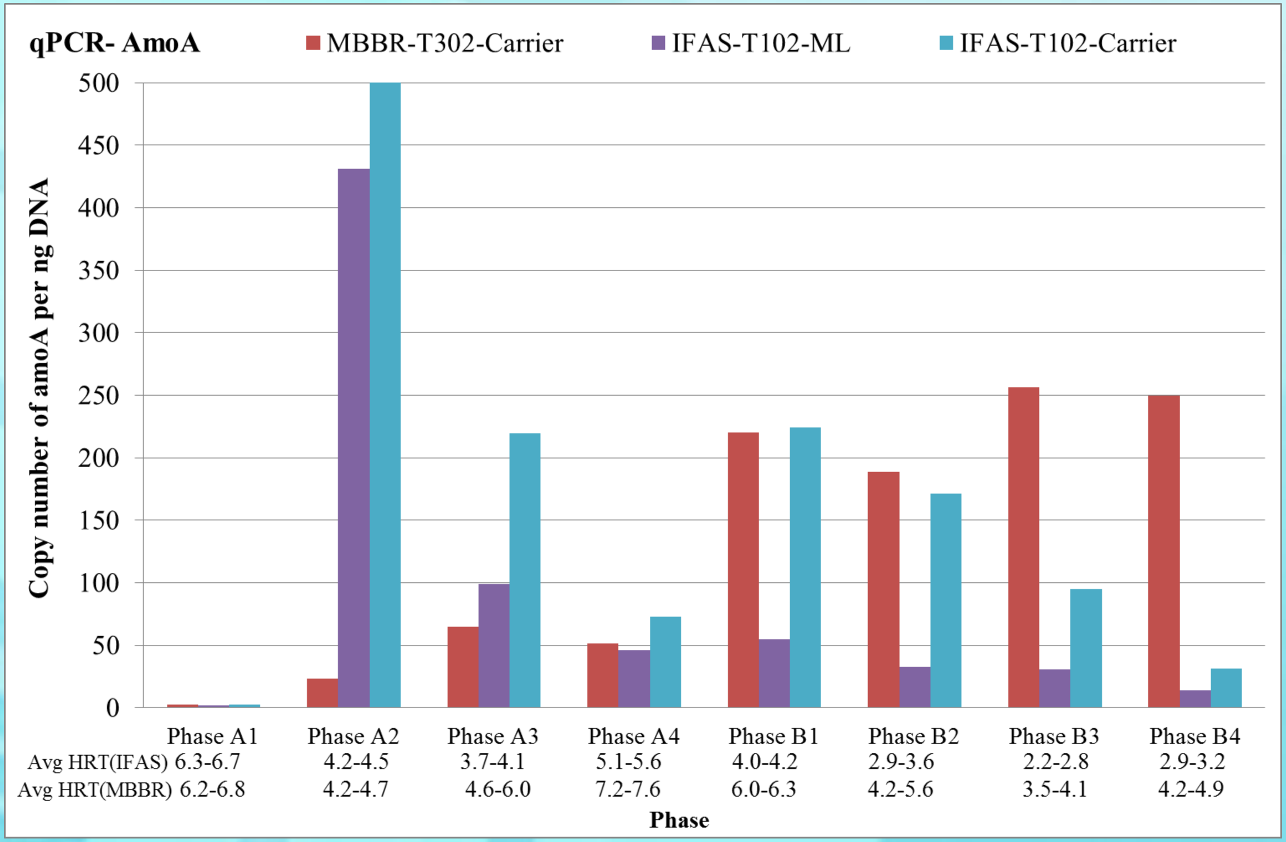
1) Substantial **attached growth biomass** for both IFAS and MBBR whereas the suspended biomass in IFAS was low.

2) MBBR carrier was *more susceptible to biomass overgrowth* under high OLR

3) MBBR had *greater biomass than* IFAS in anoxic zone. There might be room to further reduce the anoxic fraction in MBBR and in turn reduce the HRT.

Relative Amount of Nitrifiers

- Nitrifier population concentrated on biofilm carriers in aerobic zone for both systems.
- When treating CEPT effluent, MBBR actually had more nitrifiers than IFAS, but lower nitrification efficiency



Relative amount of nitrifiers in the biomass of MBBR and IFAS determined by qPCR analysis carried out by the research team of Dr. T. Zhang, Department of Civil Engineering, The University of Hong Kong.

Nitrification Efficiency

- The lower nitrification efficiency in MBBR than IFAS might possibly due to:

  - For **MBBR** under high OLR, **heterotrophic biomass grew excessively** on top of the autotrophic biomass on the mobile carriers, the biomass overgrowth could have **affected DO penetration and substrate diffusion** to the nitrifiers and impaired the nitrification activity;

  - For **IFAS**, the **influent COD** was first **removed by the suspended growth biomass** in both anoxic zone and aerobic zone of the IFAS reactor, so there was **less adverse effect of "biomass overgrowth"** on the nitrification.

Summary of Study Results

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1. At moderate HRT (~6.5 hr), IFAS could fully meet the effluent criteria of BOD, TSS, NH_3-N and TN when treating both raw sewage and CEPT effluent at 23°C.

2. FA system suffered from pH drop problem when treating CEPT effluent whereas hybrid system with pre-denitrification (IFAS) had the merits of TN removal and supplementation of alkalinity consumption and oxygen requirement.

3. Minimum HRT of IFAS and MBBR on treating raw sewage and CEPT effluent (governed by ammonia removal) at 23°C and 18°C were impressively short

Prototype System	Operating Temp.	Min. HRT (hr)	
		Raw Sewage	**CEPT Effluent**
IFAS	23°C	4.2	2.4
	18°C	5.1 – 5.6	3.1 – 3.2
MBBR	23°C	6.2	3.8
	18°C	7.2 – 7.8	4.5 – 4.9

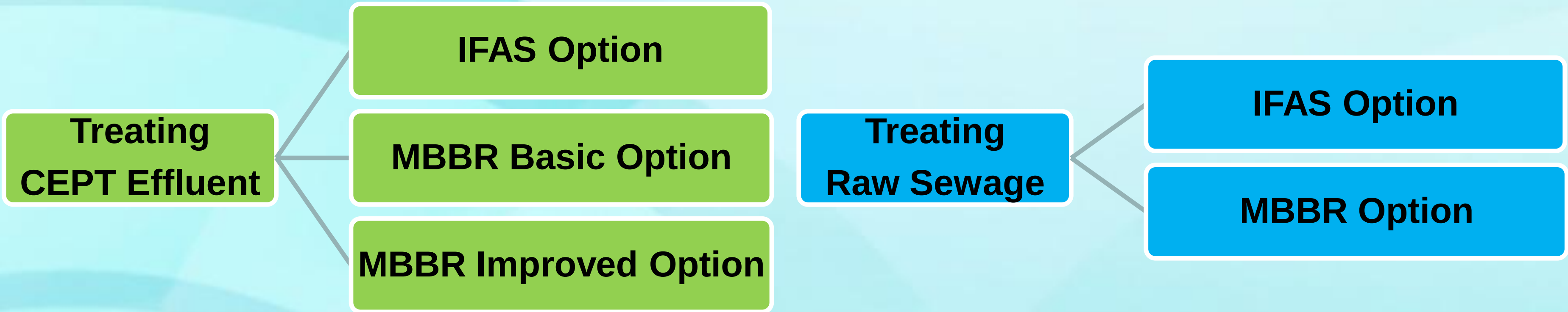
Summary of Study Results

4. When treating raw sewage under high loading, biofilm carriers are susceptible to biomass overgrowth. CEPT effluent has lower organic content but comparable nitrogen content as raw sewage. This led to lower organic loading rate (OLR), favouring higher nitrogen loading rate (NLR) and shorter HRT.

5. IFAS and MBBR have comparable and satisfactory performance:
   - Both systems showed satisfactory denitrification performance
   - IFAS had shorter minimum HRT governed by NH_3-N removal efficiency
   - MBBR showed better COD and BOD_5 removal
   - MBBR had much lower solid loading to final clarifier and better sludge settling properties, resulting in better effluent TSS

Potential Application in HATS 2B

Potential Application in HATS 2B (5 Options)



- A two-level basement, each level with a maximum floor area of about 130,000 m^2, will be designed for the additional secondary treatment for the HATS 2B. The average dry weather flow (ADWF) is about 2,441,000 m^3/d in HATS 2B.
- Only the areas for the biological reactors and final clarifiers are considered.
- The space requirement of other auxiliary equipment, like pumps, air blowers, sludge handling, odour control system and other facilities, has not yet been taken into account.
- Based on the minimum HRT for IFAS and MBBR to treat CEPT effluent and raw sewage at 18°C.

Design Options for CEPT Effluent

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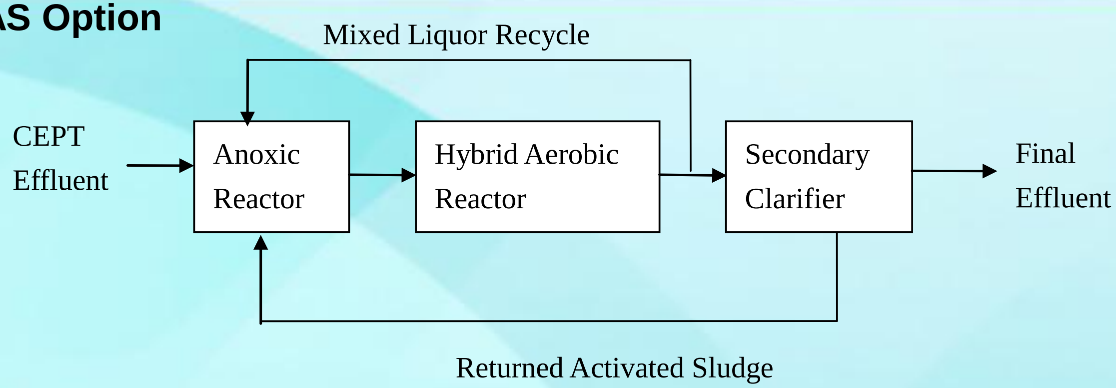
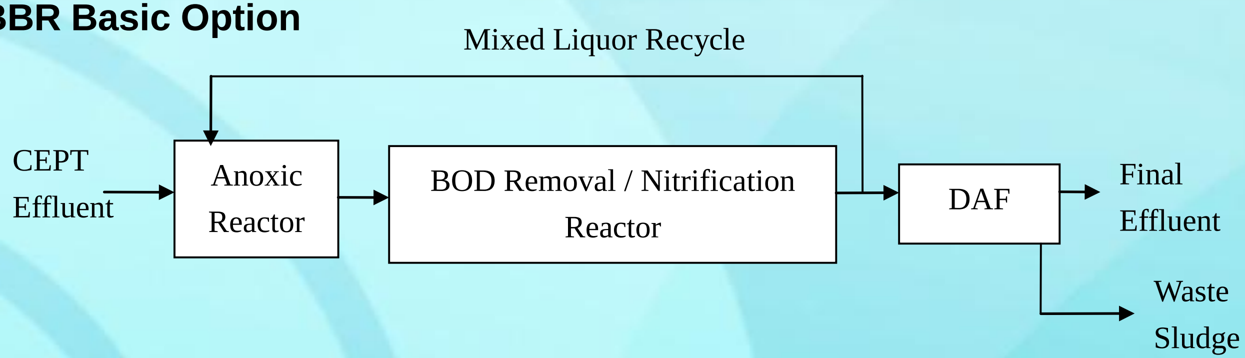
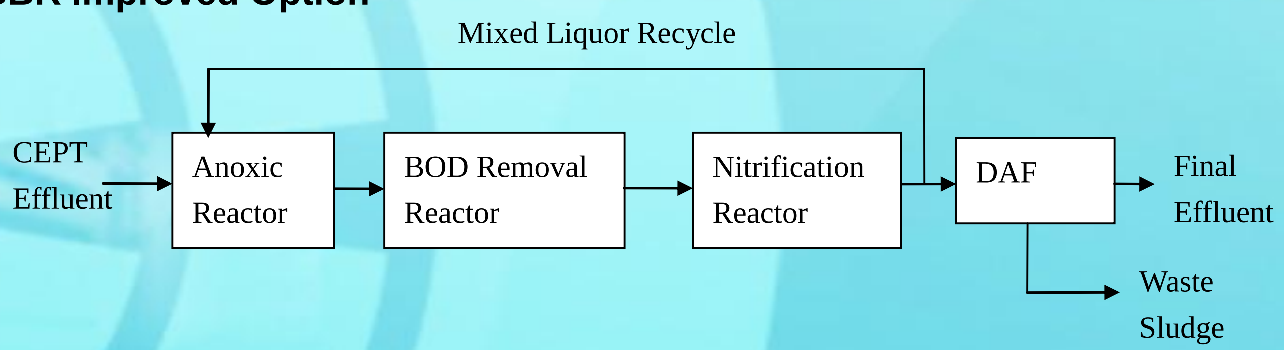
Option 1 – IFAS Option



Option 2 – MBBR Basic Option



Option 3 – MBBR Improved Option



Design Options for Raw Sewage

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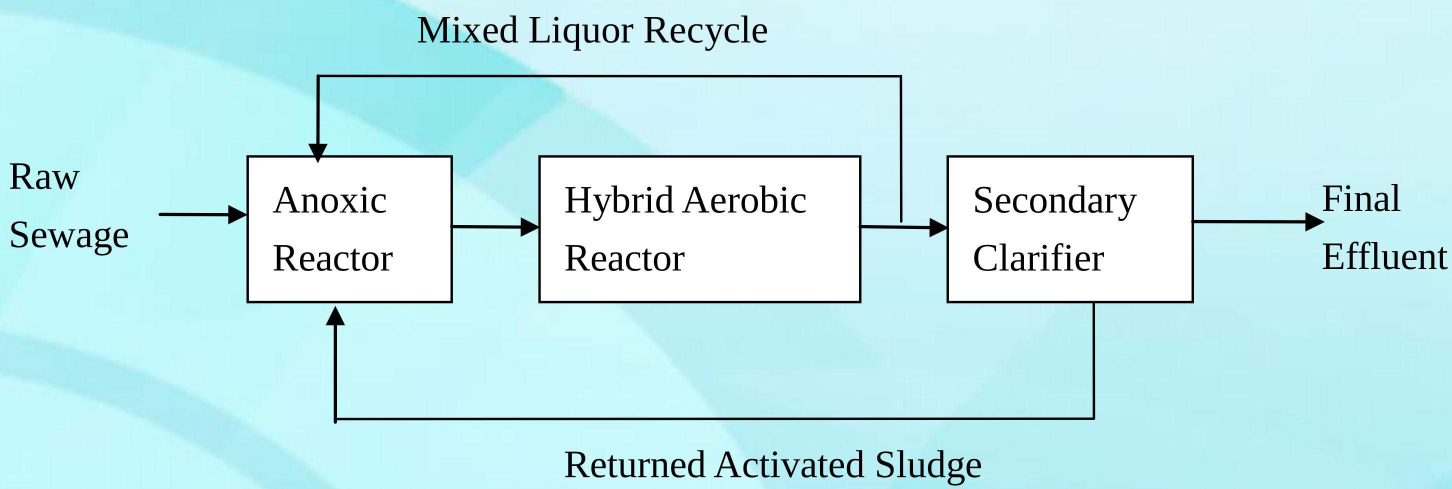
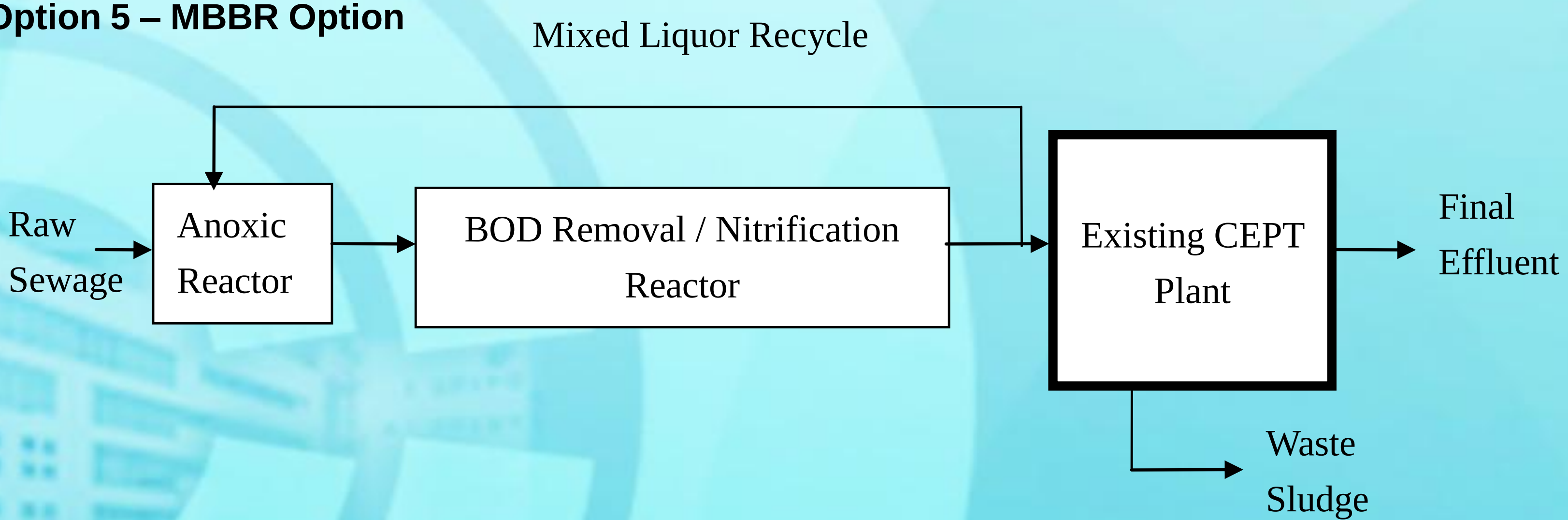
Option 4 – IFAS Option



Option 5 – MBBR Option



Footprint of IFAS and MBBR Options

Influent		CEPT Effluent			Raw Sewage	
Option		**Option 1**	**Option 2**	**Option 3**	**Option 4**	**Option 5**
	Unit	**IFAS Option**	**MBBR Basic Option**	**MBBR Improved Option**	**IFAS Option**	**MBBR Option**
Hydraulic Retention Time of Biological Reactors (Duty)	hr	3.11	4.49	3.35	5.11	7.20
Estimated floor area of Reactors (including access for maintenance)	m^2	65,200	94,200	70,200	107,100	151,000
Estimated floor area for Final Clarification (including access for maintenance)	m^2	129,600	60,000	60,000	129,600	Use existing CEPT Plant

- Based on the study results, five design options have been developed for HATS 2B for comparison. In view of space constraints, MBBR options would be more promising

Further Studies on MBBR Optimization

1) To optimize the MBBR reactor by:
   - separating the aerobic process into two stages of BOD removal and nitrification;
   - raising the DO to 5 mg/L in the nitrification reactor and so increasing the nitrification rate;
   - increasing the media fill ratio to 67% or higher, in all bioreactors;
   - optimizing the volume-fractions and HRT proportions of the anoxic, BOD removal, and nitrification reactors so that the overall system can attain a shorter minimum HRT.

2) To improve the MBBR option treating raw sewage by pre-treatment using compact solids removal technology such as fine mesh sieve filters to removing particulate material.

Thank You

Q & A