Pilot Studies on Performance of Membrane Bio-Reactor in Treating Hong Kong Freshwater and Saline Sewage and Its Virus Rejection Ability and Mechanism

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Hong Kong's Major Concerns in Wastewater Treatment

- Use of seawater in toilet flushing → High and variable salinity level in the sewage causing serious sludge bulking/foaming and limiting the disinfection means(80% toilets by seawater, 4-8 g/L Cl^-)
- Stringent discharge requirements → High Treatment Performance (TSS<30 mg/L, TN<10 mgN/L, ammonia <2 mgN/L, E.coli <1000~4000 /100mL)
- Limited land availability → Requirement of compact/space saving technologies
- Water Reclamation and Reuse → Effective and non-hazardous disinfection method

MBR Pilot Studies of HK Drainage Services Department

Sewage Treatment Works (STW)	Purpose	Membrane Type	Plant Supplier	Treatment Capacity	Period of Study	Project Amount (in JPY)	Consultant/ Contractor
Shek Wu Hui (SWH)	Sewage Treatment	Hollow fibre submerged	Mitsubishi Rayon	40 m^3/day	Dec 01 to Mar 02	4,800,00	HKUST
Stonecutters Island (SCI)	Saline Sewage Treatment	Hollow fibre submerged	Mitsubishi Rayon	40 m^3/day	Aug 02 to Nov 02	4,800,00	HKUST
Sha Tin (ST)	Centrate Treatment	Hollow fibre submerged	Mitsubishi Rayon	20 m^3/day	Jun 02 to Apr 03	20,800,000 (including plant cost)	MRC (HK)/Kingsford/HKUST
Sai Kung (SK)	Saline Sewage Treatment	Flat type submerged	Kubota	40 m3/day	Jun 02 to-Dec 02	14,400,000 (?) (including plant cost)	Yeun Fong/ATAL Eng
SWH	Water reclamation	Hollow fibre submerged with RO	Mitsubishi Rayon/Nitto Denko	40 m^3/day	Ongoing	12,800,000	HKUST

Pilot Plant Locations

Market Perspective of MBR Technology in HK

- Building wastewater recycle/reuse
- Upgrading of sewage treatment for effluent reuse (toilet flushing)
- Package plant in trade wastewater treatment (restaurants, food processing centers, etc.)

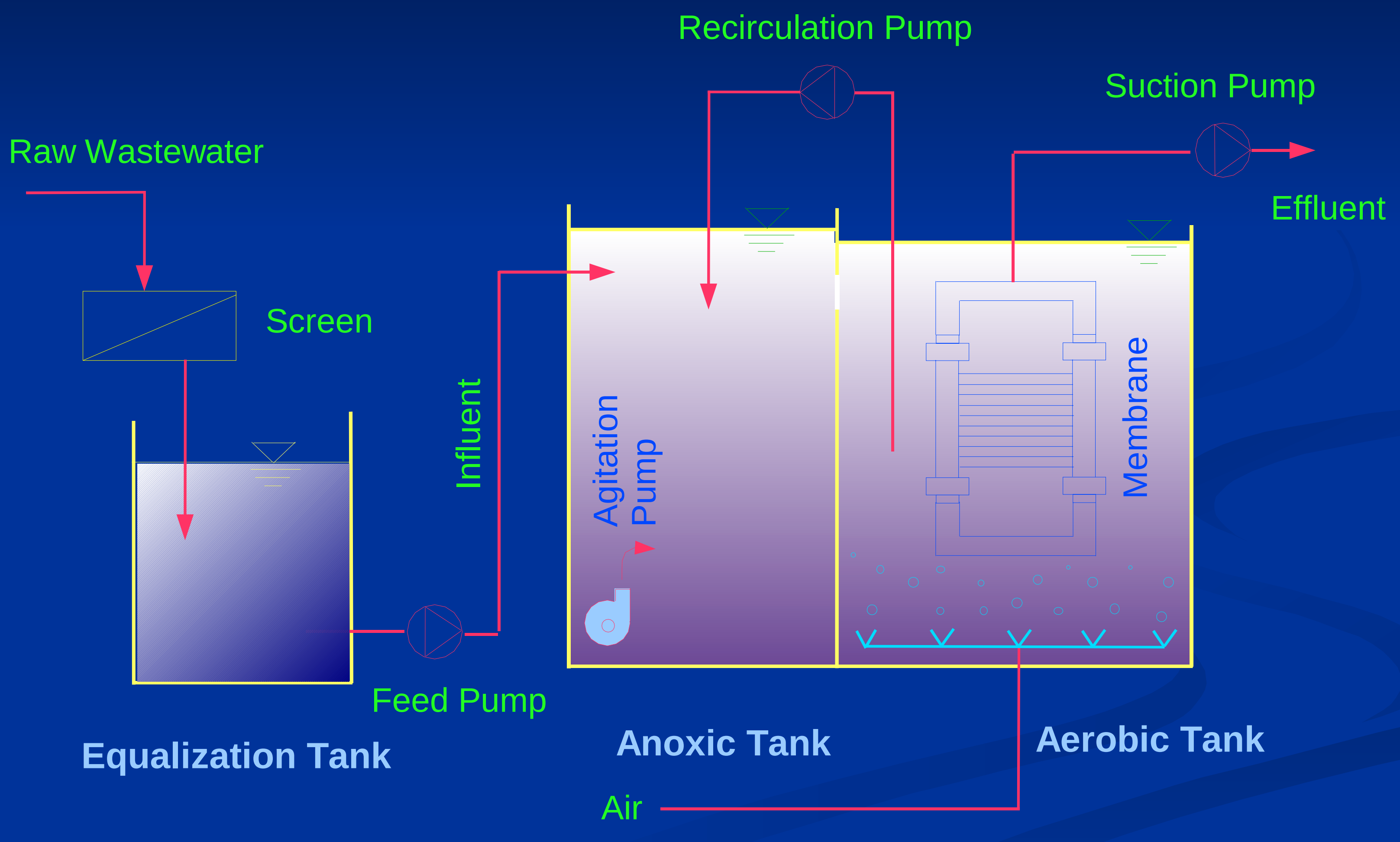
Contents of this presentation

- **Results of MBR Pilot Trials**
  - Comparison of the performances with freshwater (Shek Wu Hui STW) and saline sewage (Stonecutters Island STW Pilot Trials)
  - Treatment of Chemically Enhanced Primary Treatment (CEPT) effluent
  - Virus Rejection (Stonecutters Island STW Pilot Trial)
- **Results of MBR Laboratory Study**
  - Virus removal in a bench scale MBR: Performances and Mechanisms

Objectives of the MBR Pilot Trials at SWH STW and SCI STW

- To determine suitability of the MBR technology for the treatment of Hong Kong sewage (freshwater and saline)
- To investigate its ability to achieve carbon removal with full nitrification/denitrification to meet the discharge requirements
- To evaluate the effectiveness of the MBR for the rejection of E. coli
- To determine optimal process operation parameters under field conditions

MBR Pilot Plant



MBR Pilot Plant

MBR Configuration

Parameters	**Description**
Membrane	Hollow Fibre Membrane (Sterapore® SUR) with pore size of 0.4 μm
Total Reactor Volume	11.25 m^3
Foot Print Area	2.6 m × 3.0 m
Process Configuration	Anoxic (40%)/Aerobic (60%)
Hydraulic Capacity	40 m^3/day
Hydraulic Retention Time	7 hours
Mixed Liquor Recycle	300%
Biomass Concentration	6,000 – 12,000 mg/L
Effluent Discharge Cycle	13 minutes ON, 2 minutes OFF

MBR Pilot Trial at Shek Wu Hui Sewage Treatment Works (Freshwater)

90,000 m3/day Raw Wastewater Characteristics

Parameters	Maximum	Mean	Minimum
pH	7.6	7.1	6.5
Chloride (mg Cl^-/L)	-	-	-
Alkalinity (mg/L as $CaCO_3$)	372	235	150
BOD_5 (mg/L)	345	167	106
Total COD (mg/L)	2204	458	146
Soluble COD (mg/L)	356	220	145
TKN (mg/L)	151	53	34
TSS (mg/L)	1806	191	64
E. Coli (counts/100 mL)	5.0×10^7	1.3×10^7	2.7×10^7

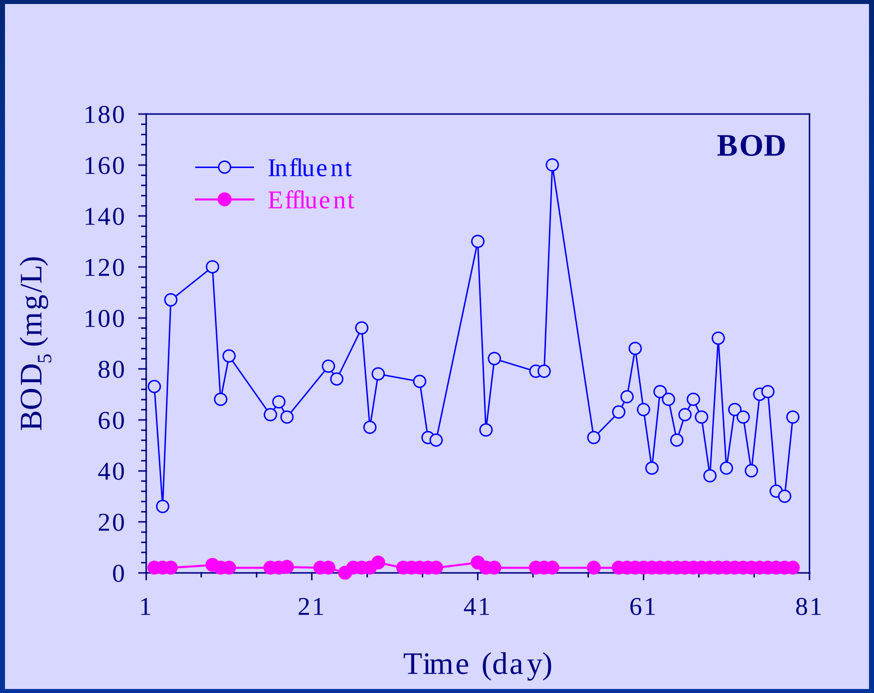
Highly variable sewage characterizes, relatively low alkalinity, and freshwater sewage

Pilot Plant Operating Conditions

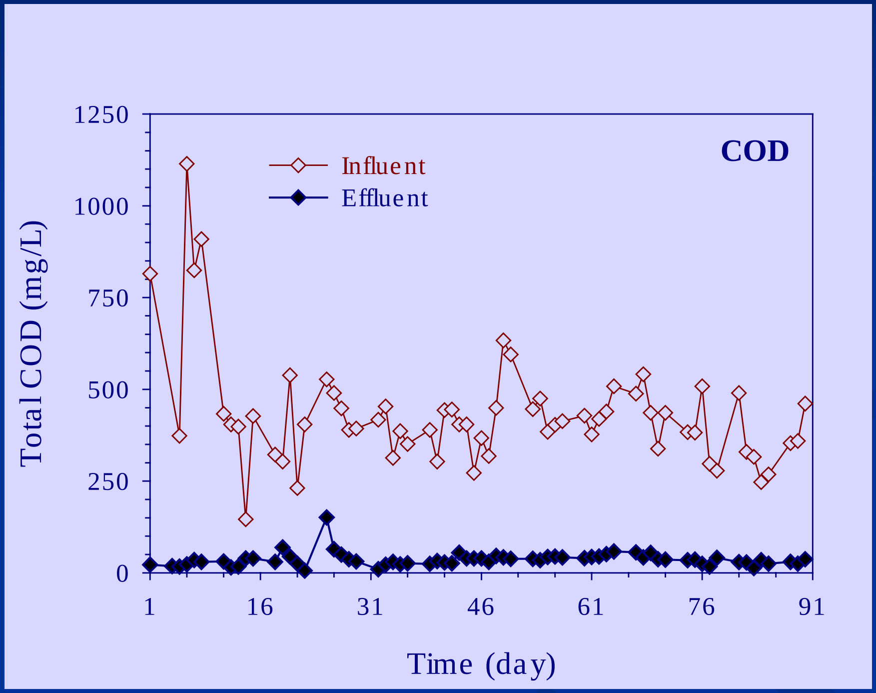
Parameters	Phase I	Phase II
HRT (hour)	6.8	6.8
Internal flow recycle	300%	300%
Average MLSS (g/L)	8.1	10.8
Average DO in aeration tank (mg/L)	2.7	2.6
F/M Ratio (kg COD/kg MLSS-day)	0.19	0.13
Volumetric Loading		
COD (kg/m^3-day)	1.54	1.40
TN (kg/m^3-day)	0.19	0.17
Wastewater Temperature (ºC)	18.1-26.9	22.0-28.3

Performance: BOD / COD Removal

BOD Removal



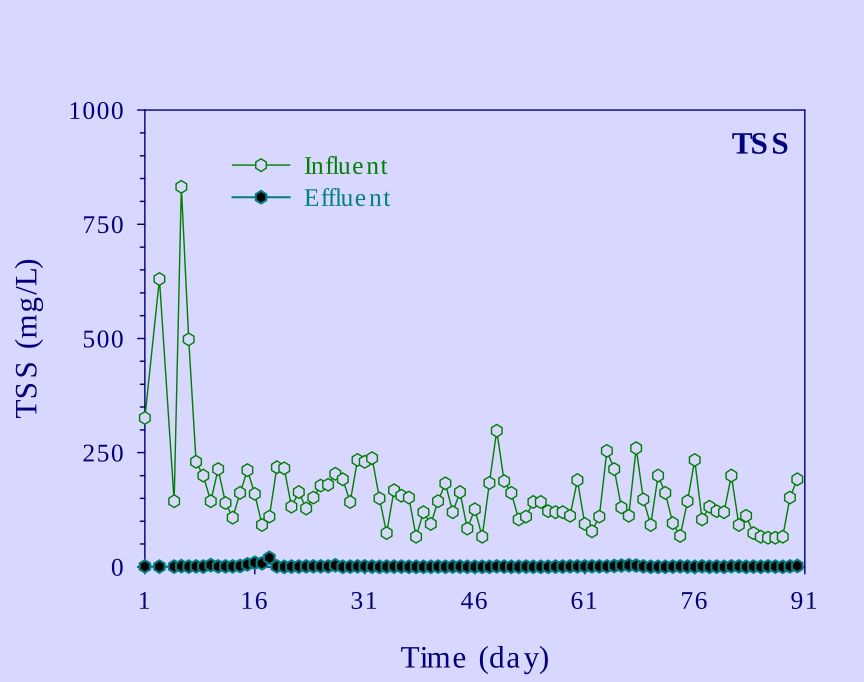
COD Removal



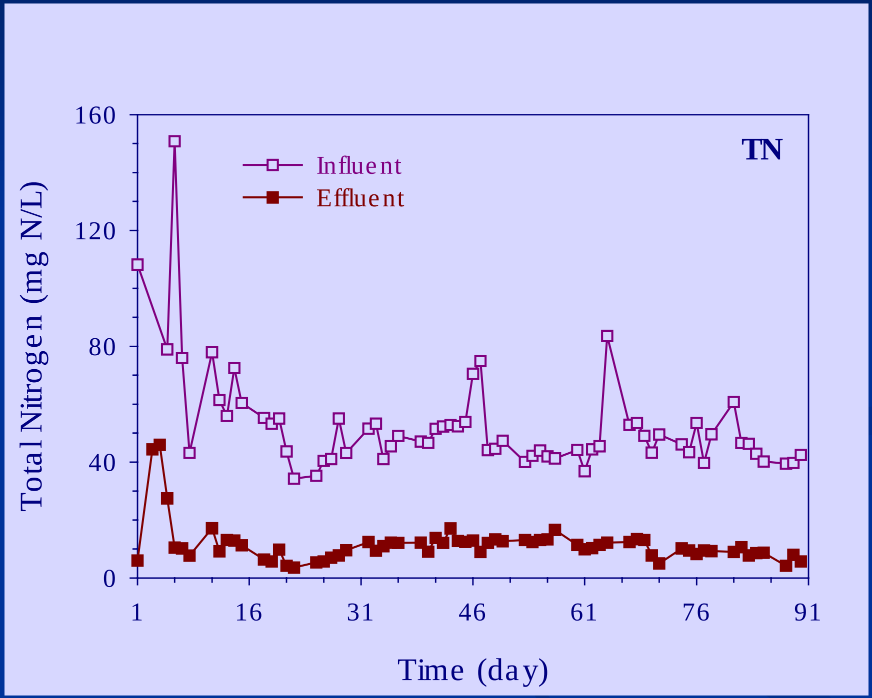
- High and stable organic removal despite high fluctuations in the raw sewage BOD and COD levels.
- Average BOD removal = 98% and average COD removal = 93%.

Performance: SS and Nitrogen Removal

Suspended Solids Removal

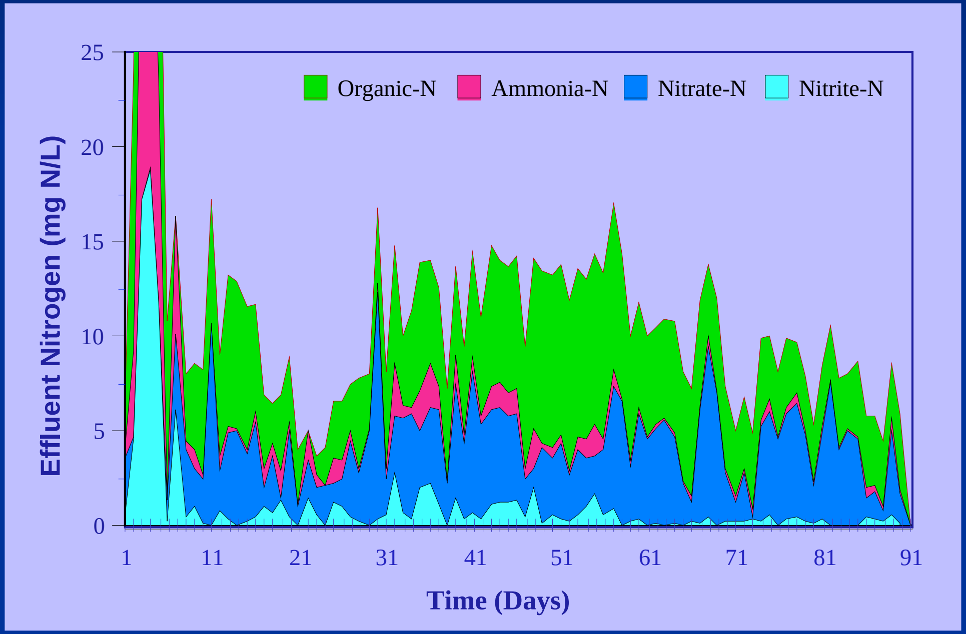


Nitrogen Removal



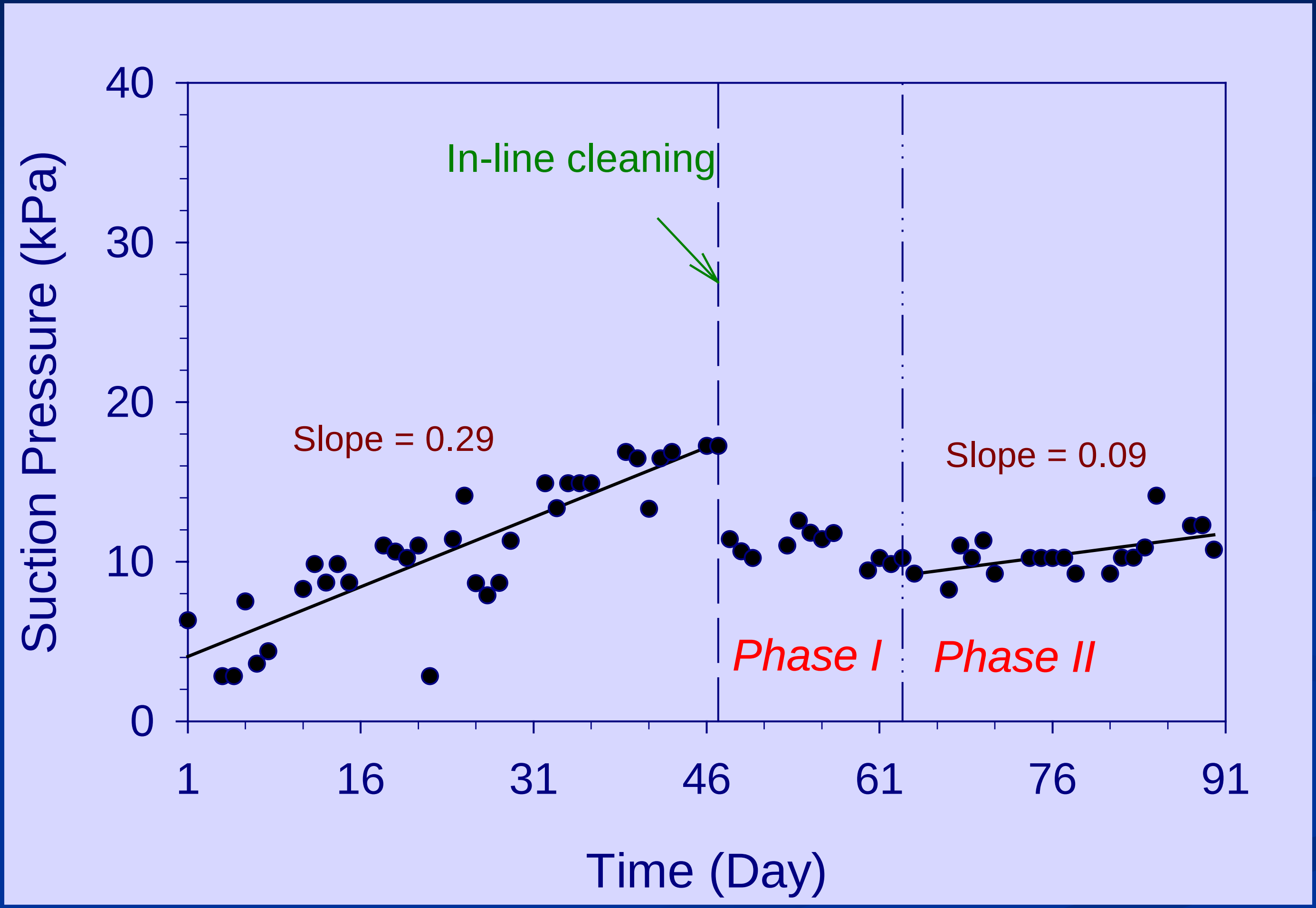
- Excellent SS and nitrogen removal.
- Average nitrogen removal = 86% with average effluent TN = 10 mg/L.
- No additional carbon source or alkalinity adjustment required.

Effluent Nitrogen Species



- The effluent mostly contained organic nitrogen and nitrate nitrogen
- The proportion of different nitrogen species varied considerably
- Higher nitrate → Incomplete denitrification
- Higher organic nitrogen → presence of slowly hydrolyzed organic nitrogen in the raw sewage

Transmembrane Pressure



MBR Pilot Trial at Stonecutters Island Sewage Treatment Works (saline)

1,400,000 m3/day Raw Wastewater Characteristics

Parameters	Maximum	Mean	Minimum
pH	7.7	7.0	6.4
Chloride (mg Cl^-/L)	7870	5916	3500
Alkalinity (mg/L as $CaCO_3$)	576	275	114
BOD_5 (mg/L)	410	186	62
Total COD (mg/L)	1032	515	152
Soluble COD (mg/L)	612	280	80
TKN (mg/L)	130	38	18
TSS (mg/L)	896	206	26
E. Coli (counts/100 mL)	2.9×10^8	3.5×10^7	1.2×10^7

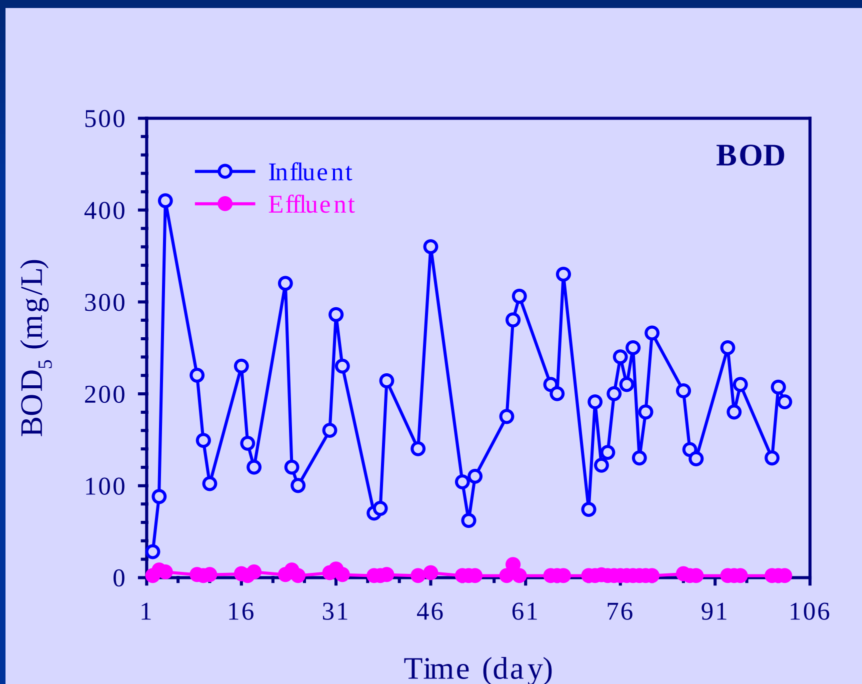
Highly variable sewage characterizes, relatively low alkalinity, and saline sewage

Pilot Plant Operating Conditions

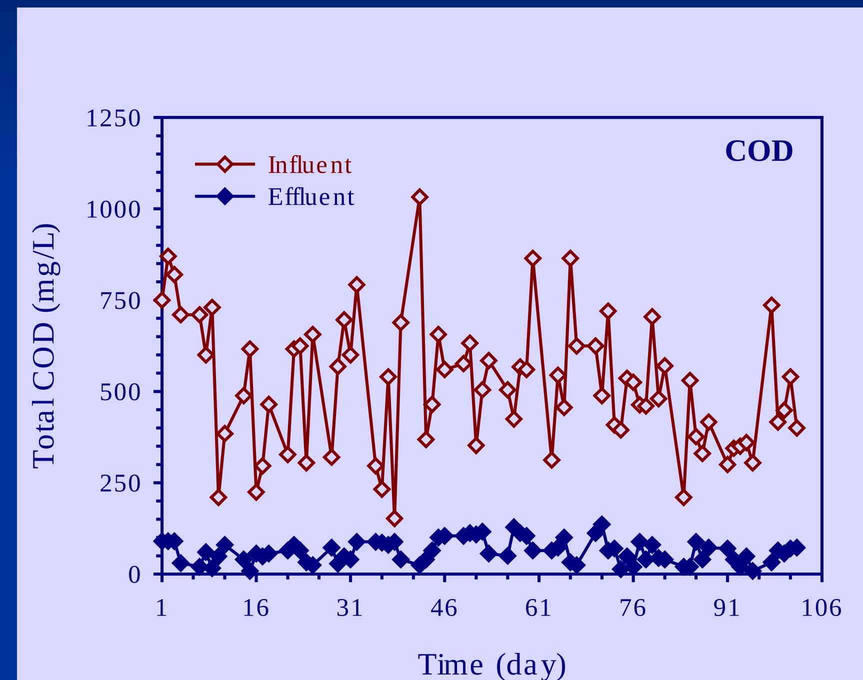
Parameters	Phase I	Phase II
HRT (hour)	6.8	6.8
Internal flow recycle	300%	300%
Average MLSS (g/L)	8.4	12.3
Average DO in aeration tank (mg/L)	2.9	2.4
F/M Ratio (kg COD/kg MLSS-day)	0.23	0.14
Volumetric Loading		
COD (kg/m^3-day)	1.93	1.72
TN (kg/m^3-day)	0.14	0.13
Wastewater Temperature (ºC)	26.3-28.8	24.9-28.8

Performance: BOD / COD Removal

BOD Removal



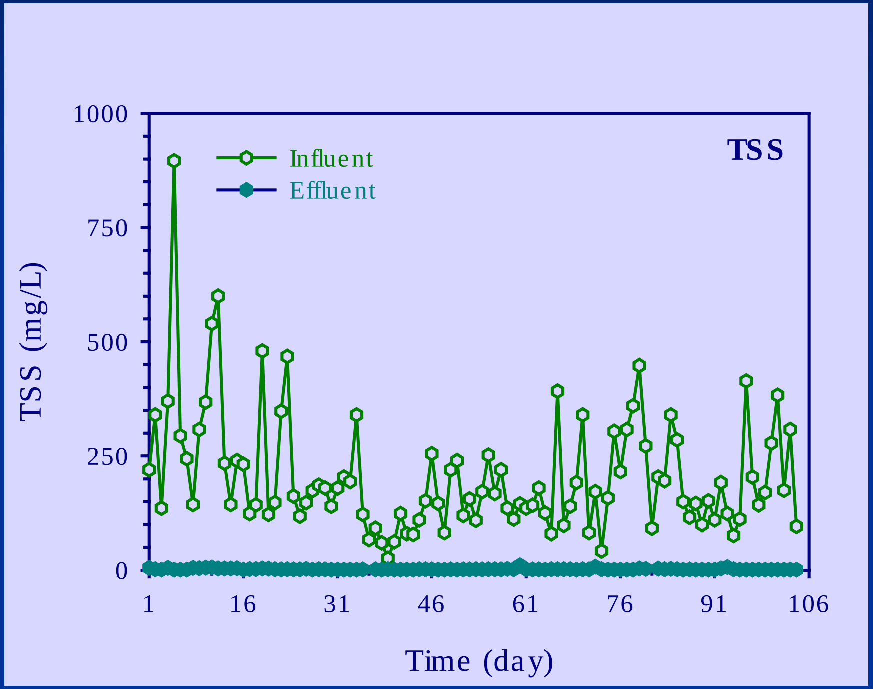
COD Removal



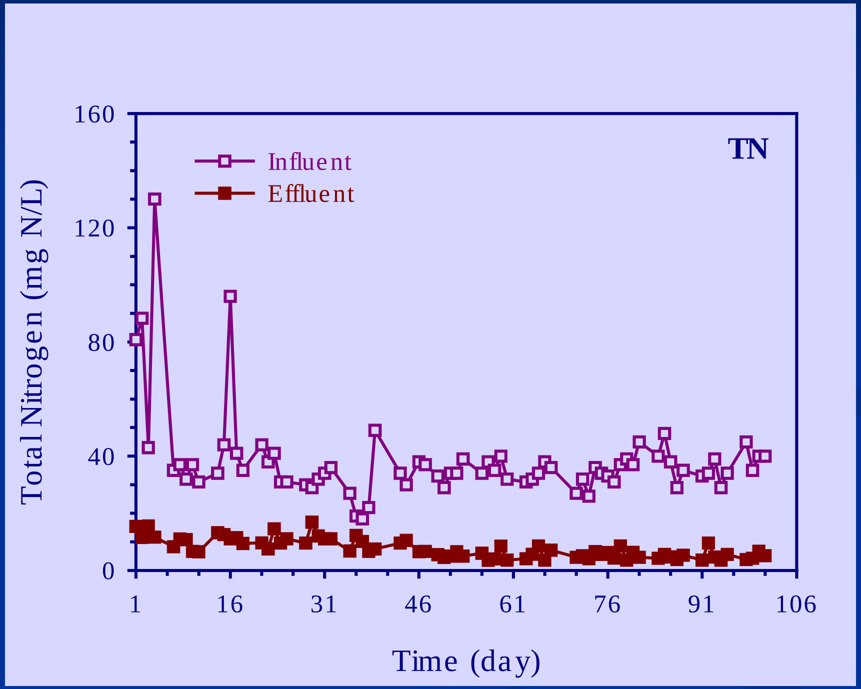
- High and stable organic removal despite high fluctuations in the raw sewage BOD and COD levels.
- Average BOD removal = 98% and average COD removal = 93%.

Performance: SS and Nitrogen Removal

Suspended Solids Removal

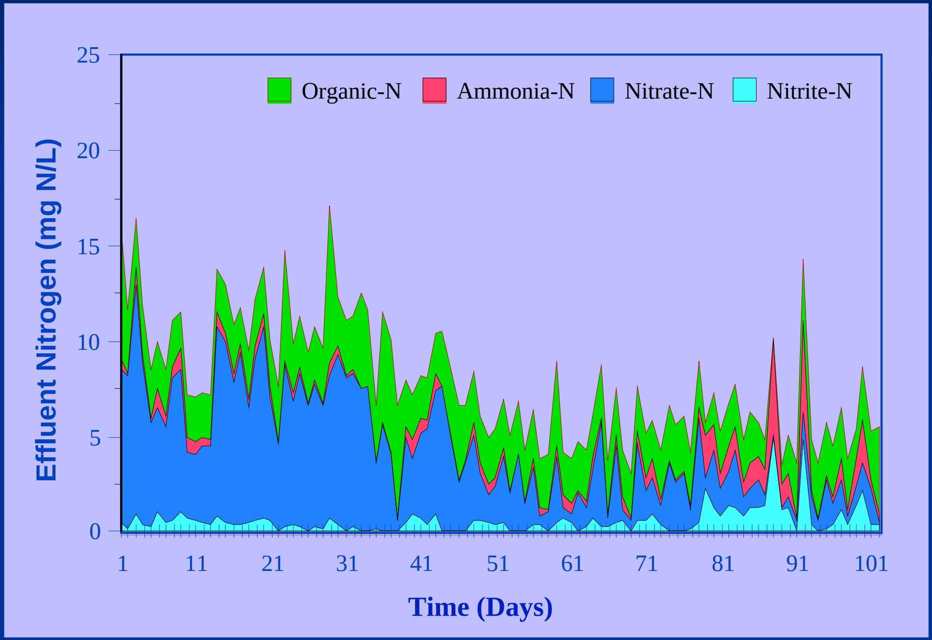


Nitrogen Removal



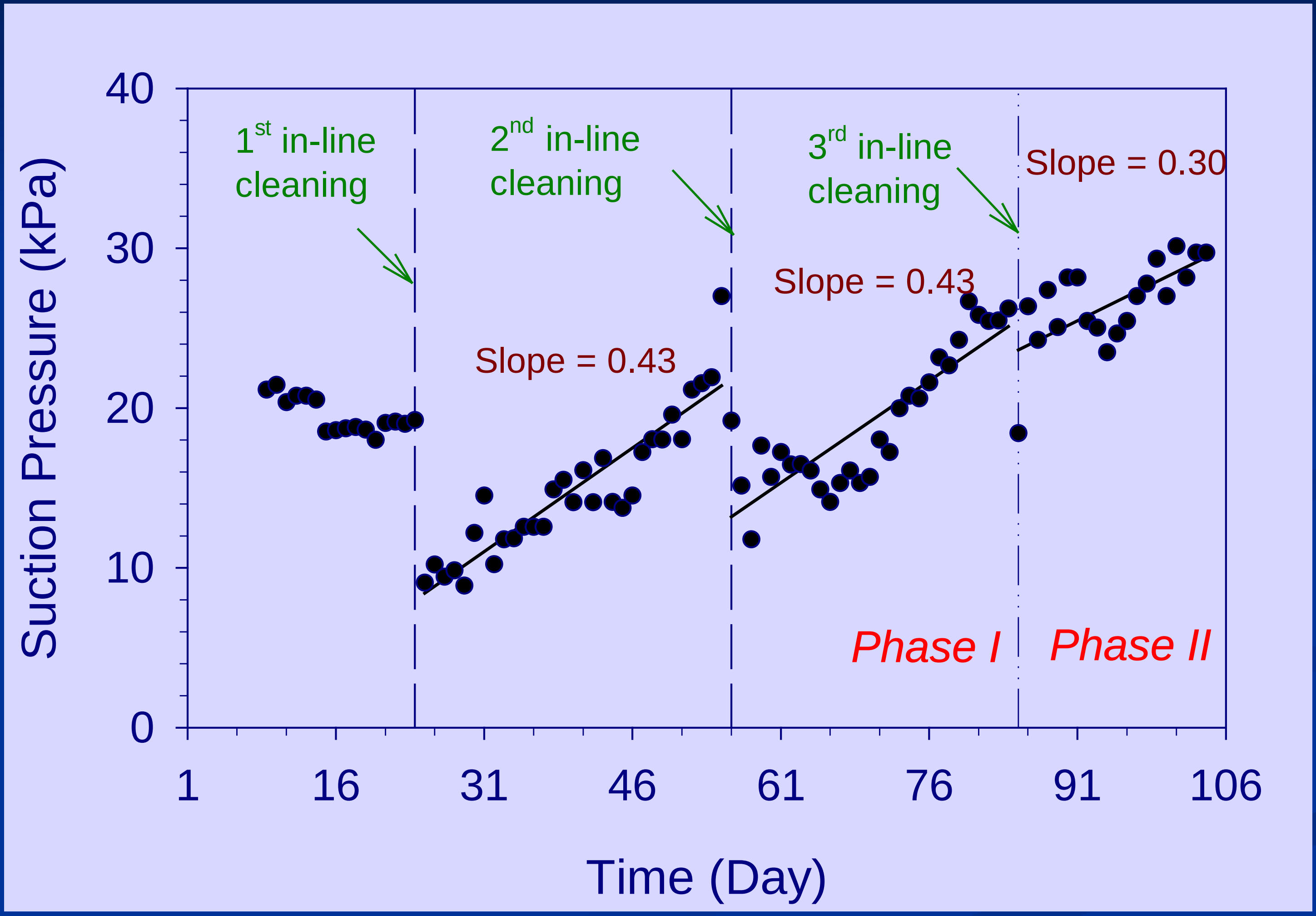
- Excellent SS and nitrogen removal.
- Average nitrogen removal = 82% with average effluent TN = 7.6 mg/L.
- No additional carbon source or alkalinity adjustment required.

Effluent Nitrogen Species



- The effluent mostly contained organic nitrogen and nitrate nitrogen
- The proportion of different nitrogen species varied considerably
- Higher nitrate → Incomplete denitrification
- Higher organic nitrogen → presence of slowly hydrolyzed organic nitrogen in the raw sewage

Transmembrane Pressure

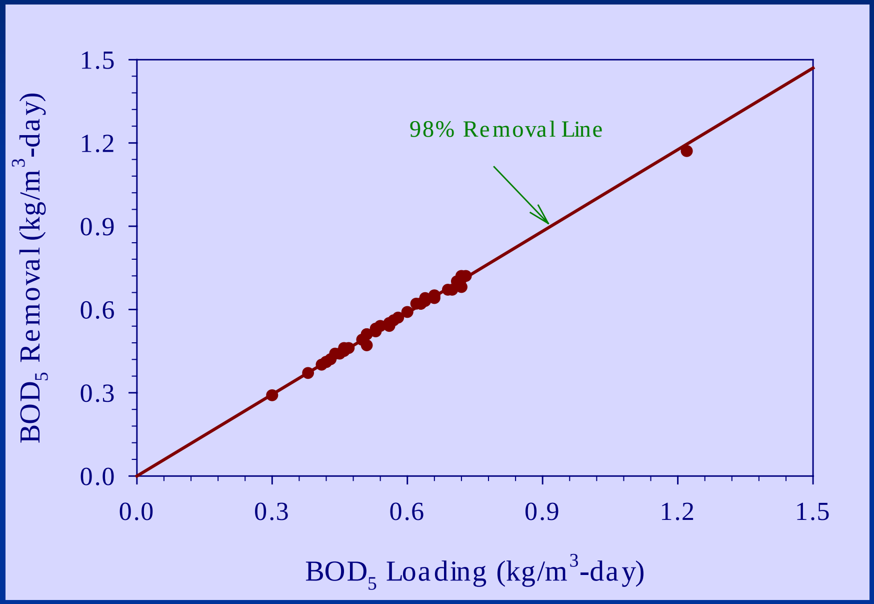


Membrane Cleaning

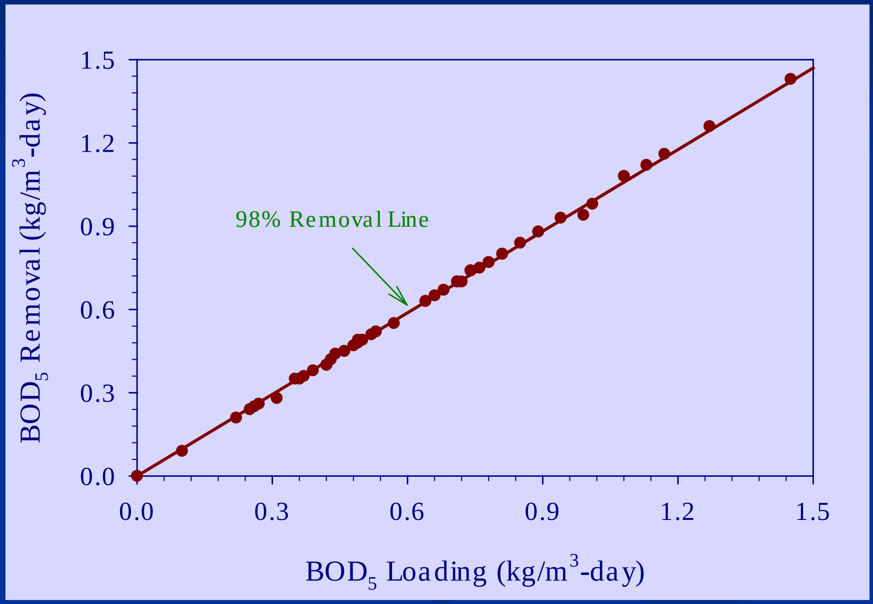
- Fine bubble aeration was used to prevent the membrane fouling by shearing off the biofilm
- The shearing off was further facilitated by intermittent withdrawal of the effluent at a timed cycle of 13 min ON and 2 min OFF
- Periodic in-line cleaning with sodium hypochlorite
- Off-tank membrane cleaning with sodium hypochlorite and sodium hydroxide solution

Effect of Loading on BOD Removal

Shek Wu Hui STW (Freshwater Sewage)



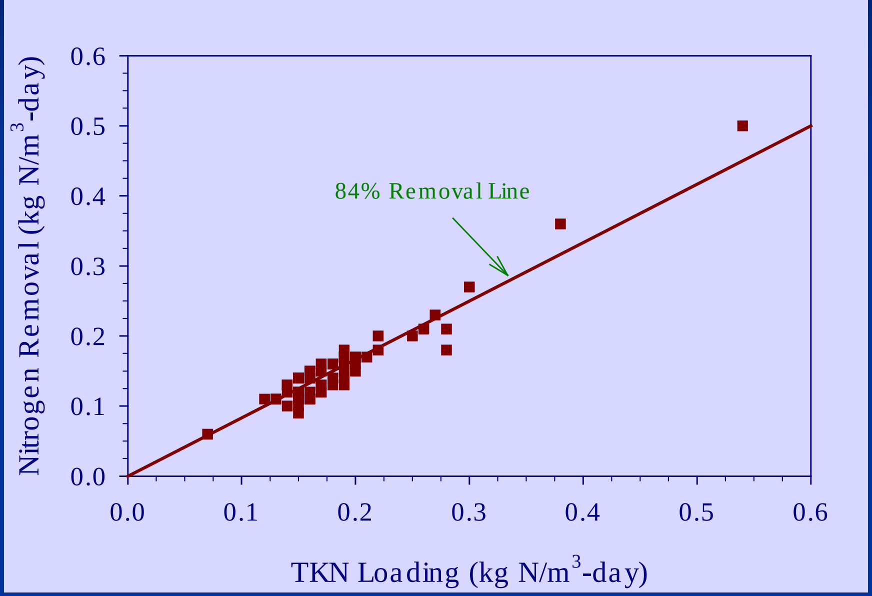
Stonecutters Island STW (Saline Sewage)



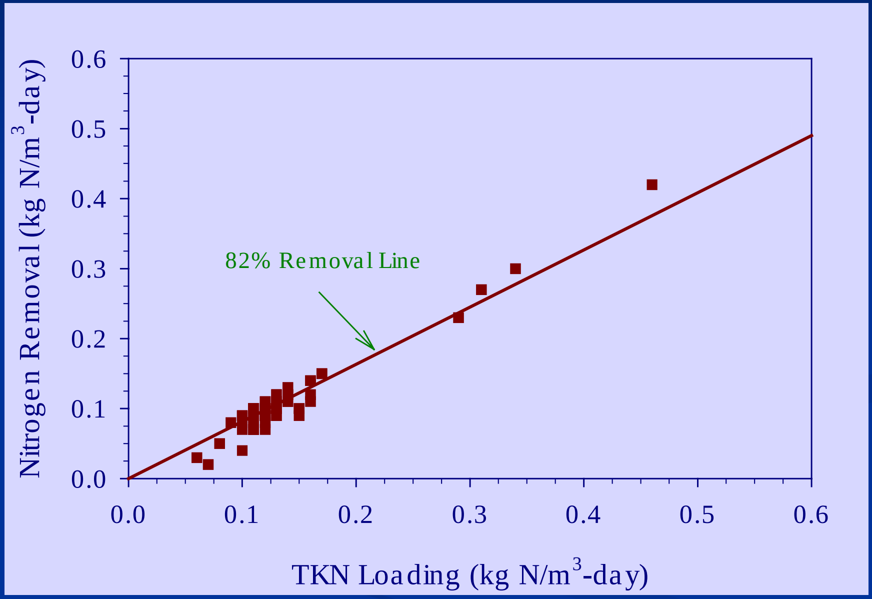
- No significant difference in the performance with freshwater and saline sewage.
- The removal capacity of the MBR was limited by the loading rather than the bioactivity.

Effect of Loading on Nitrogen Removal

Shek Wu Hui STW (Freshwater Sewage)



Stonecutters Island STW (Saline Sewage)



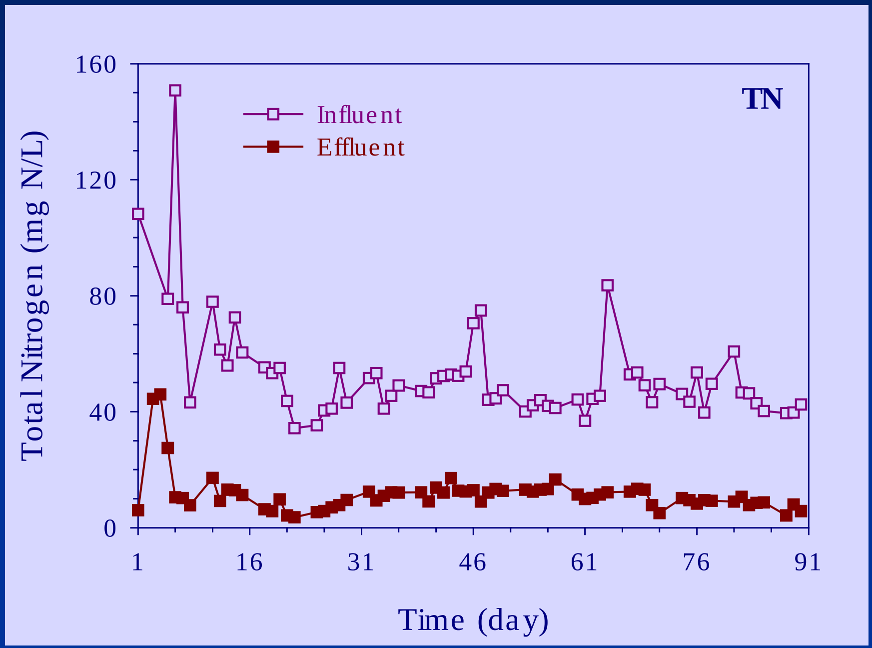
- No significant difference in the performance with freshwater and saline sewage.
- The nitrogen removal capacity of the MBR was limited by the loading rather than the bioactivity.

Treatment of Freshwater and Saline Sewages

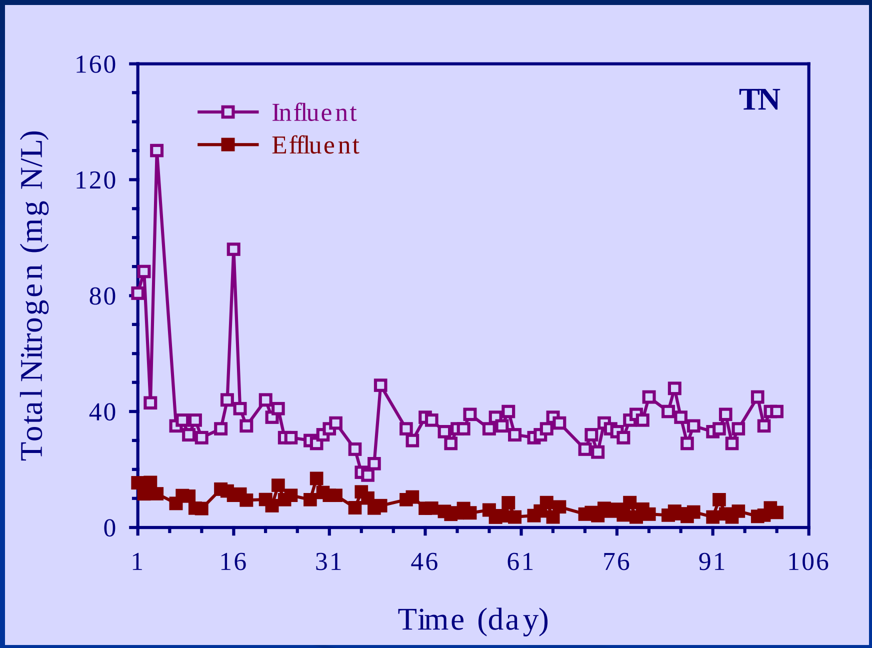
Comparison of Performance

Nitrogen Removal

Shek Wu Hui STW (Freshwater Sewage)



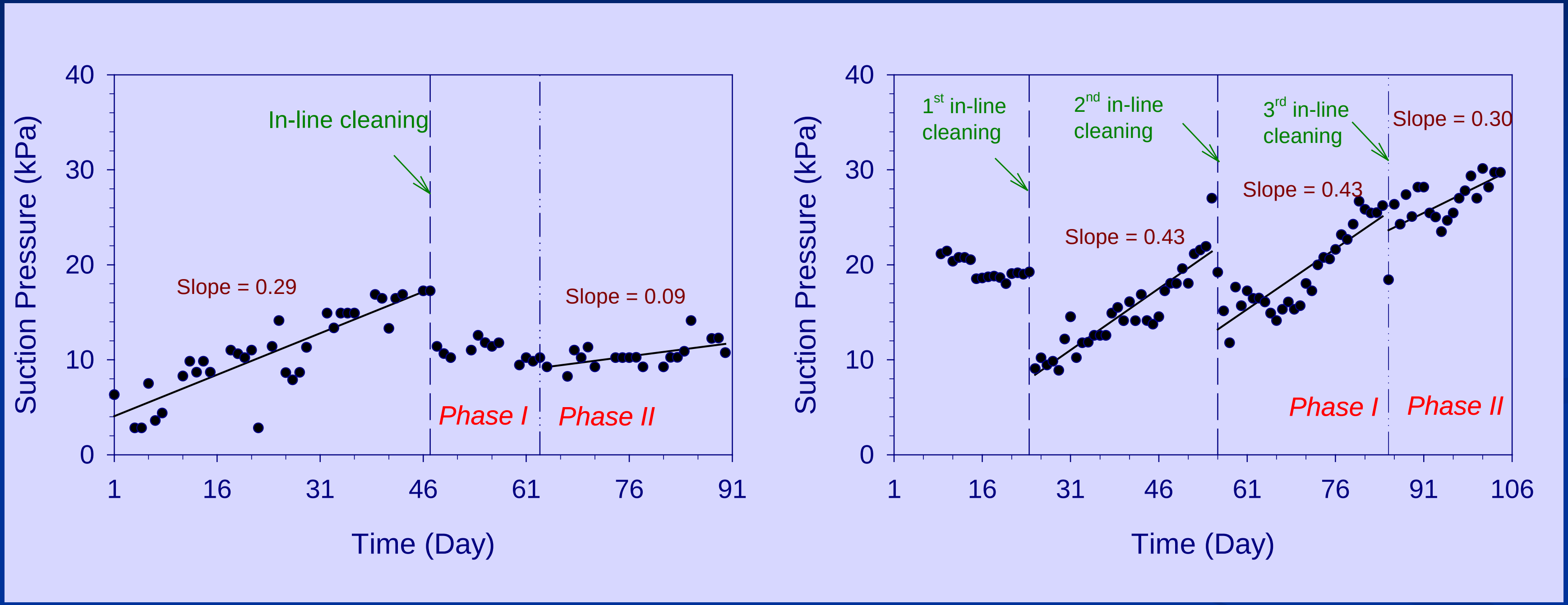
Stonecutters Island STW (Saline Sewage)



- Both the pilot plant showed excellent nitrogen removal.
- The average effluent total nitrogen for Stonecutters Island STW MBR was lower than that for the Shek Wu Hui STW MBR. This was possibly due to high influent TKN and a high TKN/COD ratio in the former case.
- The change in biomass concentration did not show any significant effect on the nitrogen removal performance.

Transmembrane Pressure

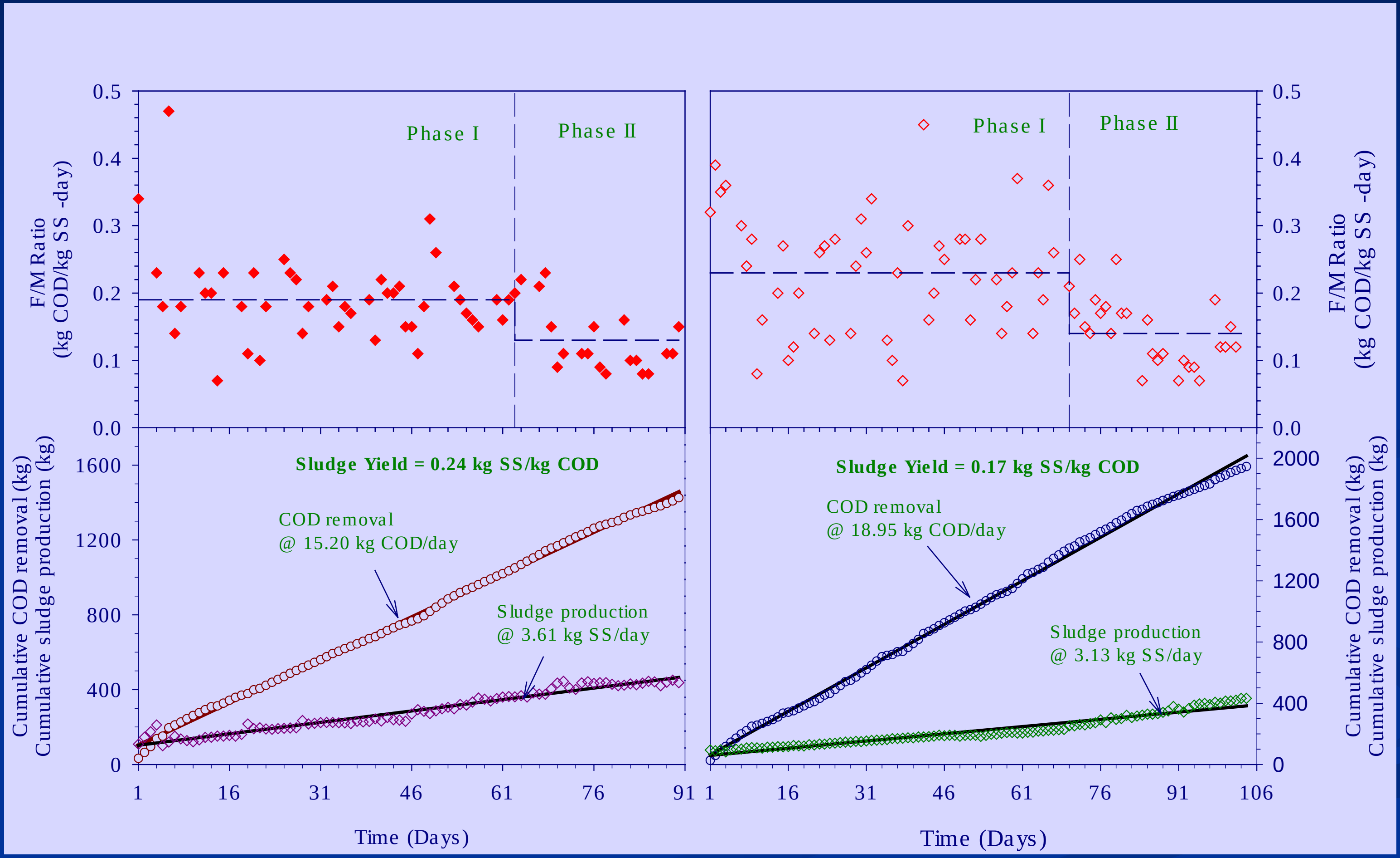
Shek Wu Hui STW (Freshwater Sewage) Stonecutters Island STW (Saline Sewage)



- The rate of pressure build-up was higher for the saline sewage than the freshwater sewage.
- After 3 month of operation, in-line chemical cleaning was not effective for saline sewage.
- The treatment of saline sewage required more frequent membrane cleaning.

Sludge Production

Shek Wu Hui STW (Freshwater Sewage) | Stonecutters Island STW (Saline Sewage)

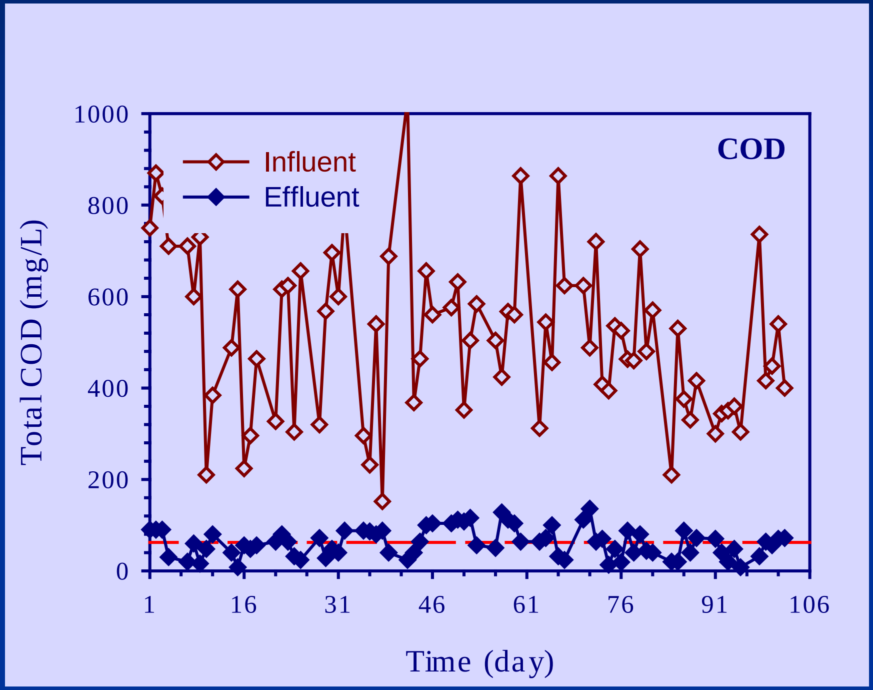


- The observed sludge yields were relatively low (0.17-0.24 kg SS/kg COD removed)

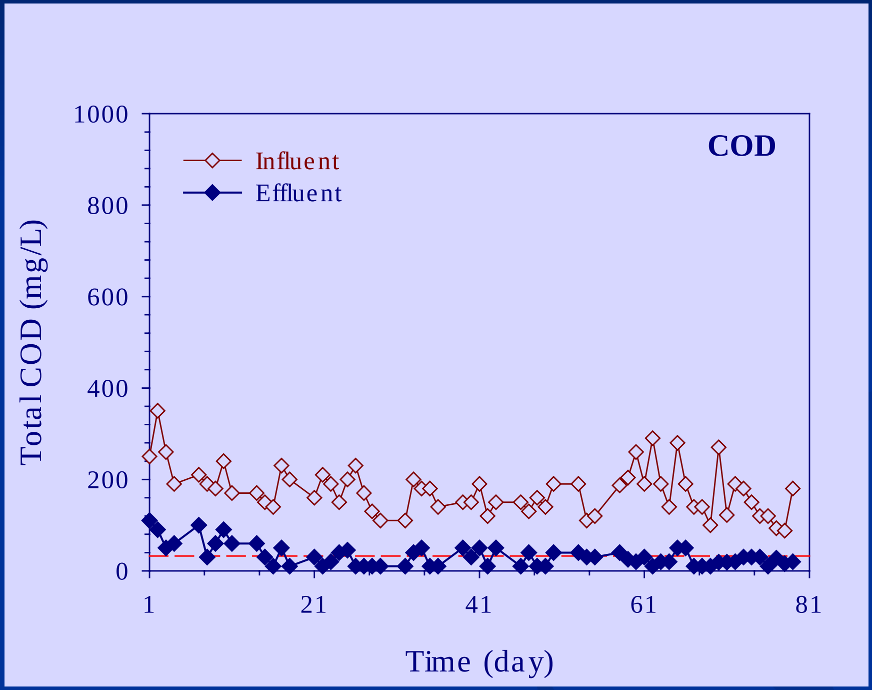
Treatment of Chemically Enhanced Primary Treatment (CEPT) Effluent of SCISTW

Treatment of CEPT Effluent

Treatment of Raw Sewage



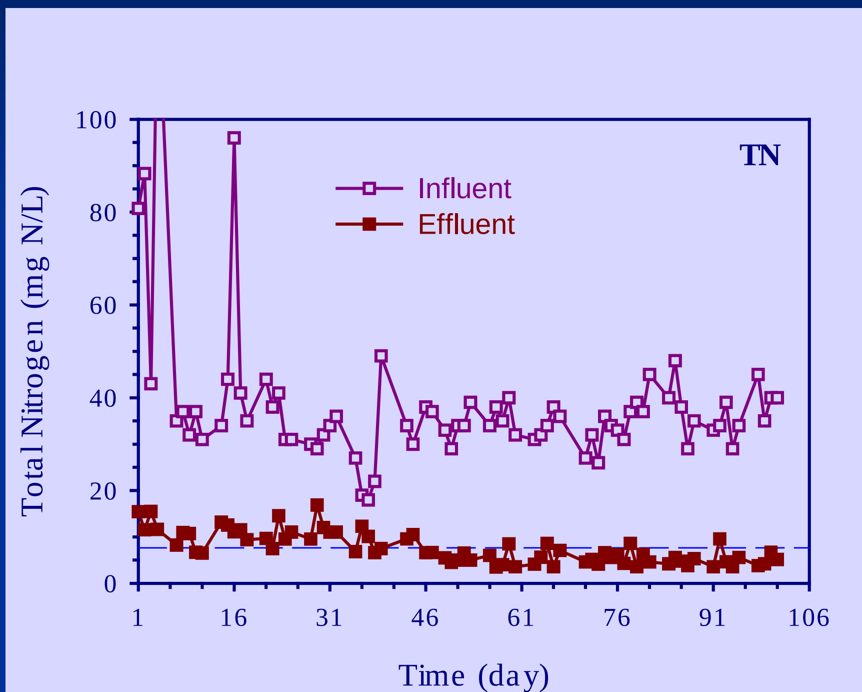
Treatment of CEPT Effluent



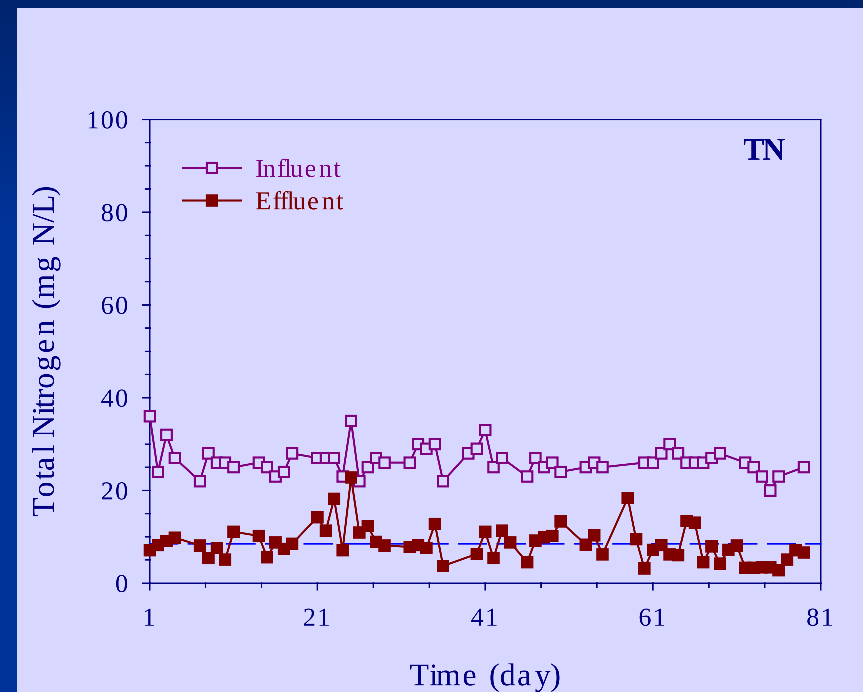
- The COD was much lower in the CEPT effluent than the raw sewage.
- The performance of the MBR treating the CEPT effluent was better in terms of the effluent COD. This was possibly due to the removal of a portion of inert COD during the CEPT.

Treatment of CEPT Effluent

Treatment of Raw Sewage



Treatment of CEPT Effluent

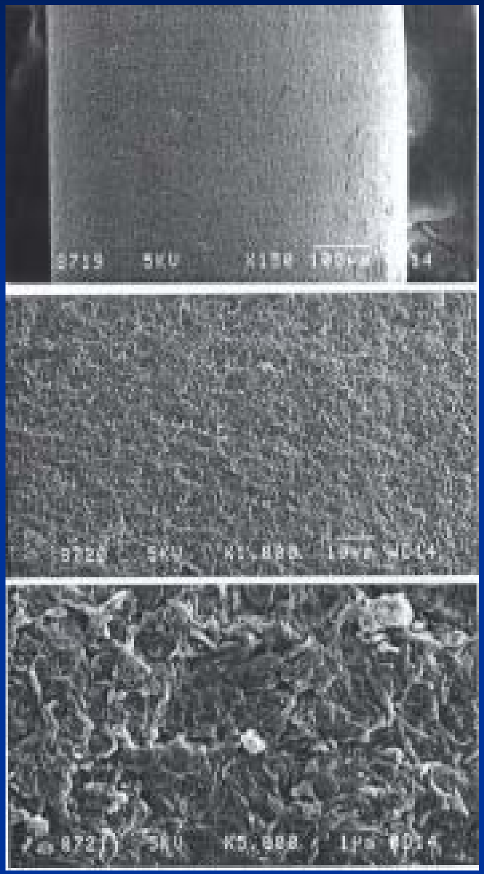


- The TKN concentration for the CEPT effluent was much lower than that for the raw sewage.
- The effluent TN was somewhat higher in the treatment of CEPT effluent. This was possibly due to insufficient carbon source in the CEPT effluent.

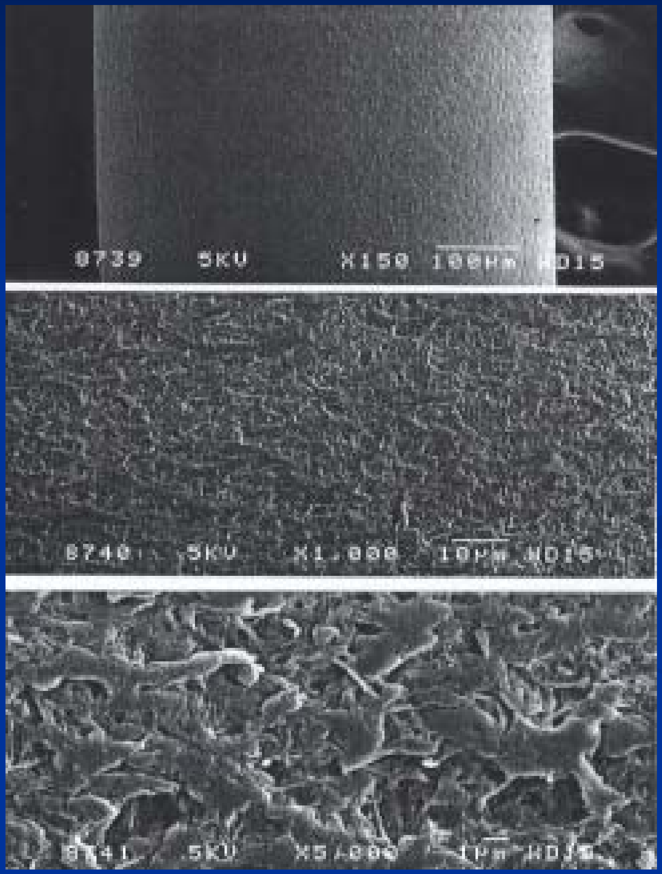
Membrane Cleaning

- The increase in suction pressure was much faster in the treatment of CEPT effluent than that for of raw sewage.
- Normal NaOH + NaOCl cleaning (off-tank) was not effective in this case. The membrane required frequent cleaning (every three weeks).
- Acid cleaning followed by NaOH + NaOCl cleaning was tried instead and it was found effective in controlling the membrane fouling.
- The results indicated that the intensity of fouling was much severe in the treatment of CEPT effluent, possibly due to the deposition of inorganic materials on the membrane surface.

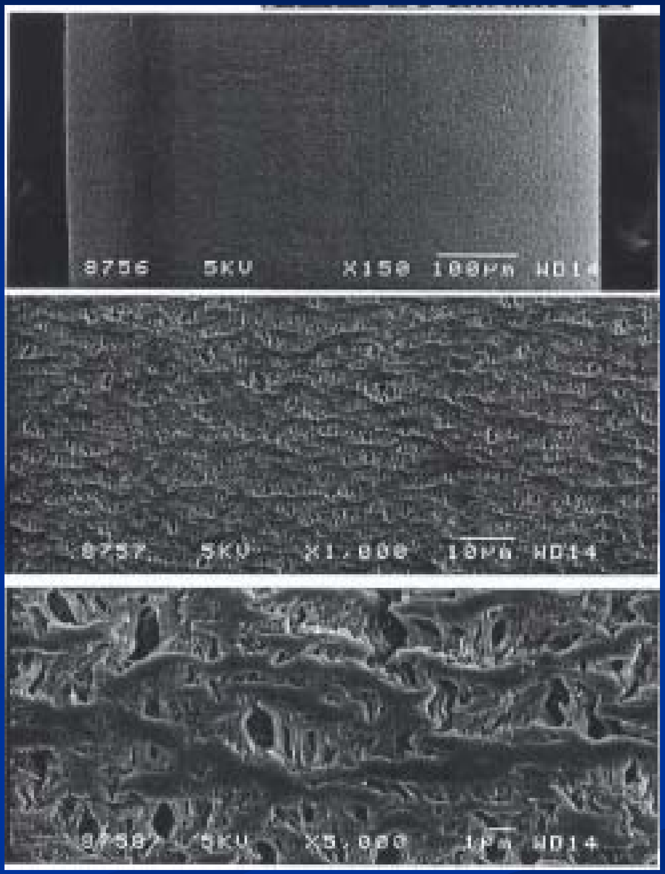
SEM Results



Before Cleaning



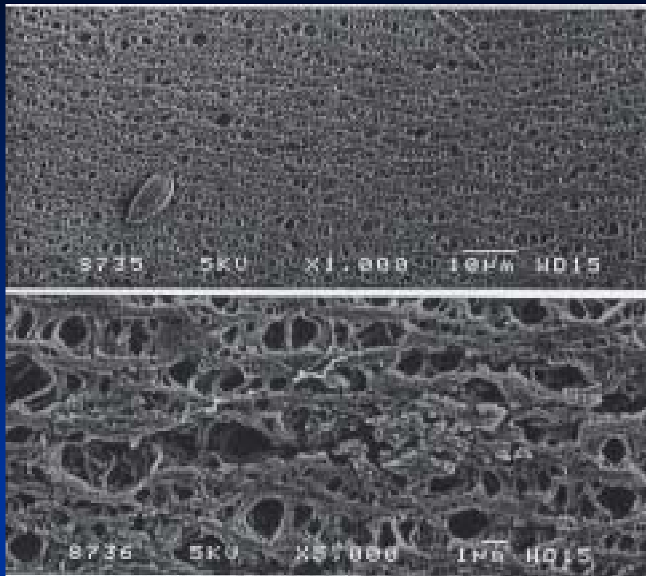
After Alkali Cleaning



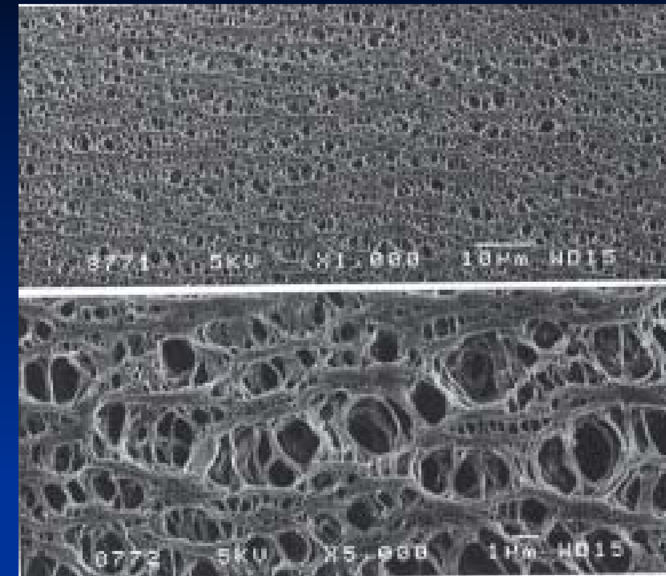
After Acidic Cleaning

Outer Membrane Surface

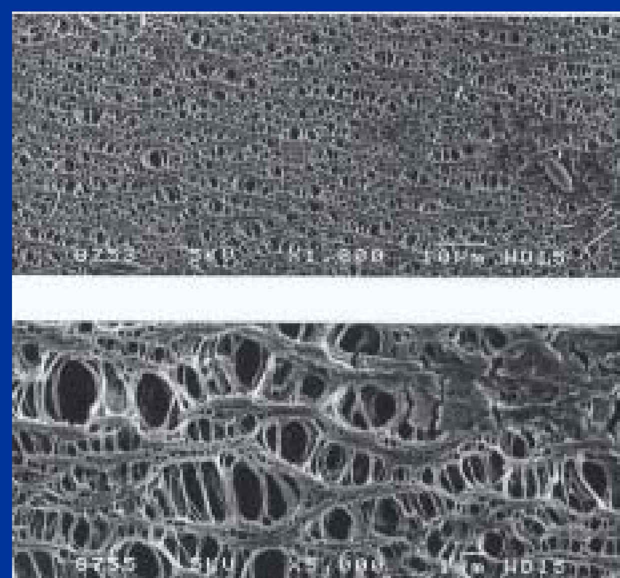
Inner Membrane Surface



Before Cleaning



After Acidic Cleaning



After Alkali Cleaning

Virus Rejection Ability of MBR and Its Mechanism

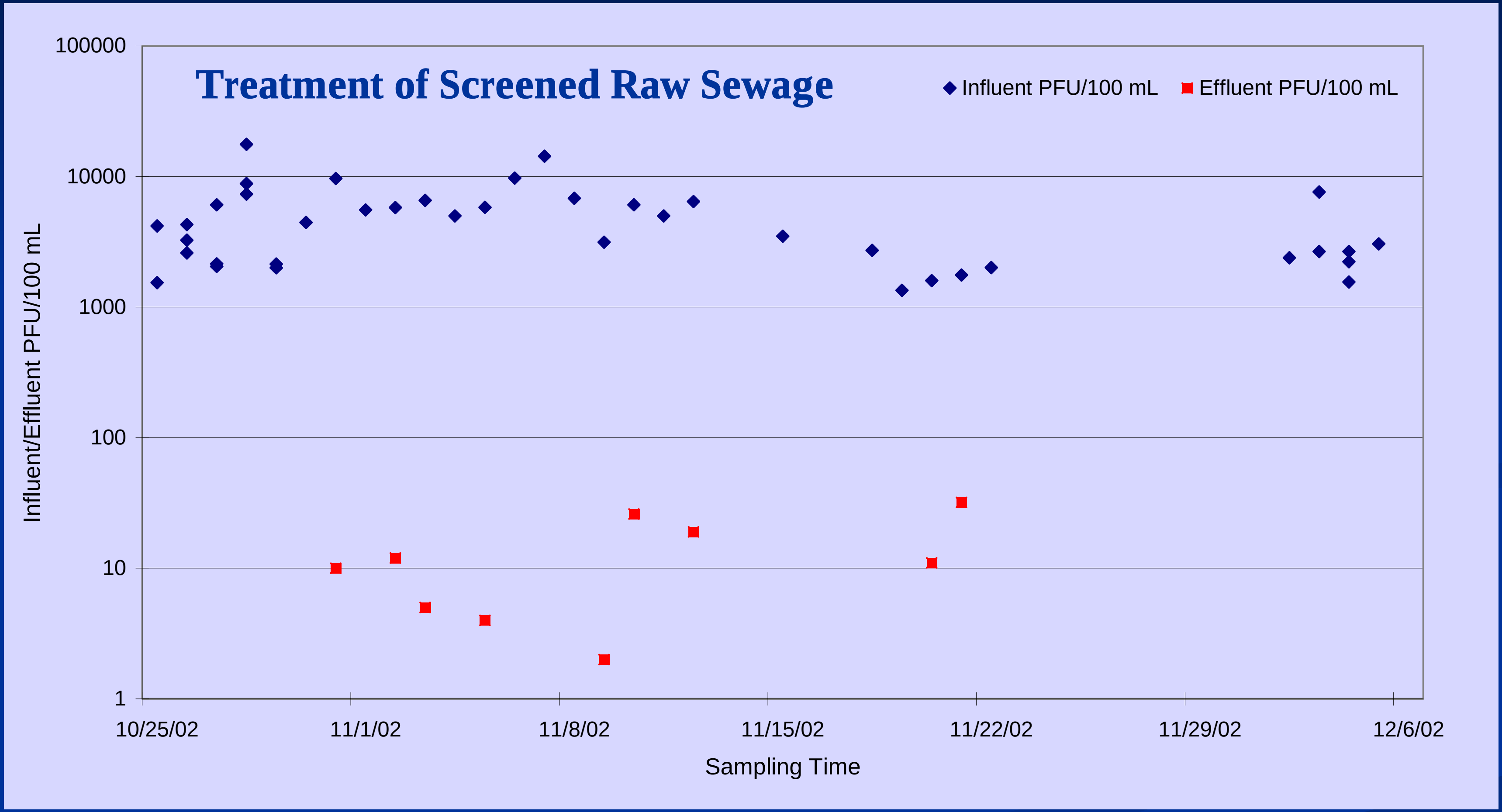
HK Wastewater Disinfection

- Wastewater needs to be disinfected so as to inactivate or partially destruct waterborne disease-causing microorganisms (<1000 to 4000 E.Coli/ml)
- Chlorination is the most common method, but produces carcinogenic by-products
- Other methods like UV radiation is being applied but very expensive
- MBR may provide effective, non-hazardous alternative biological/physical disinfection credits for sewage, particularly for saline sewage.

Virus as a Pathogen Indicator

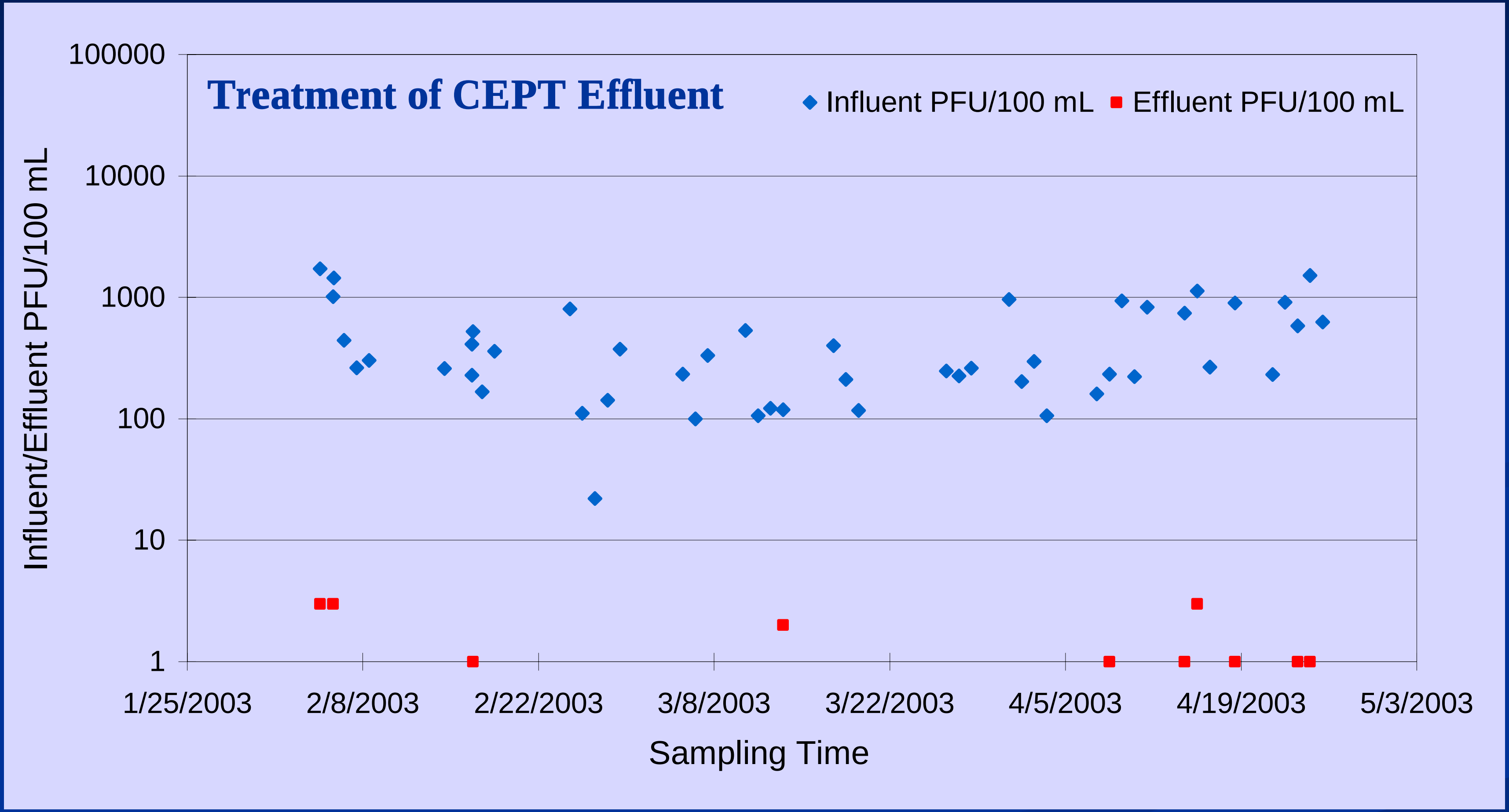
- Epidemiological (disease transmission) significance of viral pathogens
- Viruses are smaller (0.02 ~ 0.3 μm), hard to be strained and more resistant to disinfectants than bacteria (Leong, 1983)
- Using classical bacterial indicator is therefore not adequate and viral indicator should be applied
- Viral Indicators: MS-2 bacteriophage (~0.025 μm) adopted in this study
- Viral enumeration method: Single/Double Agar Layer Method (Adams, 1959)

MBR Pilot Trial: Virus Removal



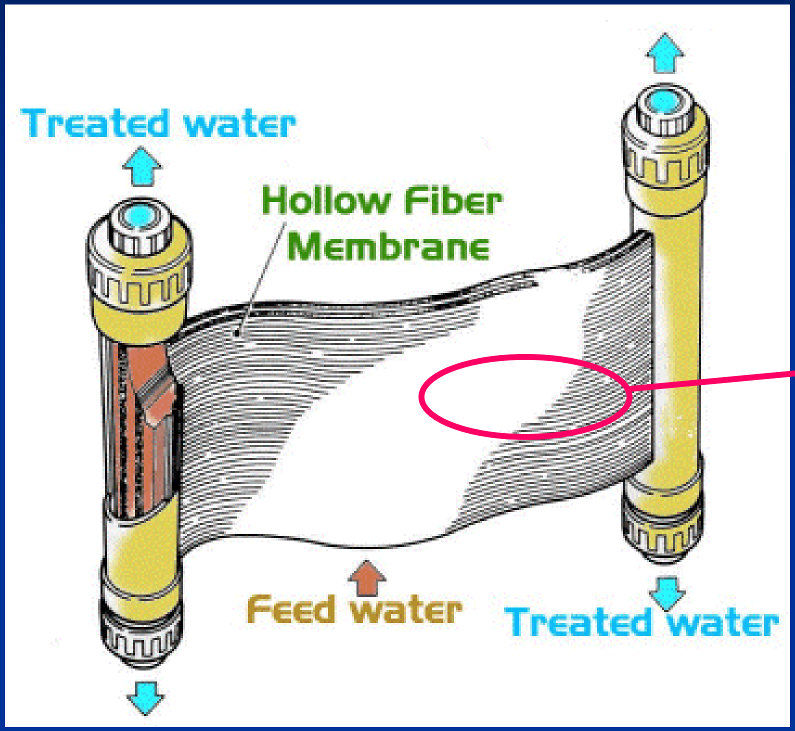
- If there is no effluent virus count shown in the figure, this means virus was not detected.
- A 2.5-3.5 log removal of virus was observed.

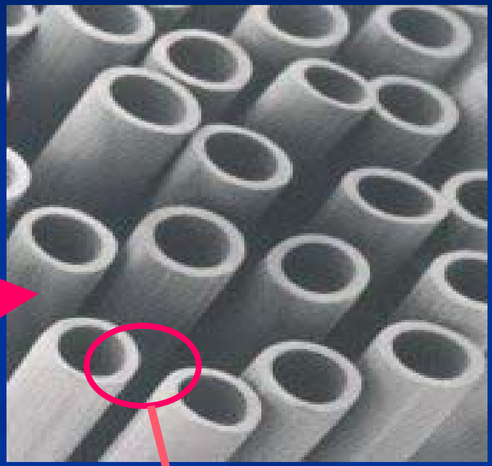
MBR Pilot Trial: Virus Removal

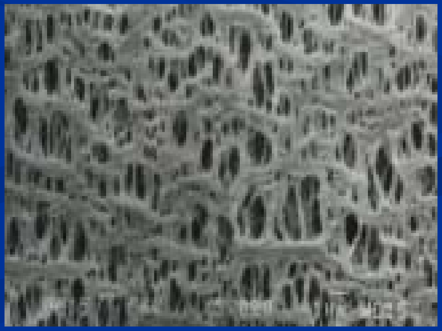


- If there is no effluent virus count is shown in the figure, this means virus was not detected.
- A 2.5-3.5 log removal of virus was observed.

Hollow Fibre Membrane







Membrane pore size = 0.40 µm, virus size = 0.02 – 0.10 µm

Almost complete rejection of viruses by MBR indicates that the physical straining is not an appropriate mechanism of virus rejection.

Objectives of the Lab Study on Viral Removal of MBR

- To evaluate feasibility of utilizing submerged MBR as a pre-disinfection process
- To study factors affecting the viral removal

  Factors such as MLSS concentration, sludge age, suction pressure, and membrane cleaning.

- To investigate mechanisms of the viral removal

  Role of mixed liquor suspended solids and the biofilm development on the membrane surface.

Study Approach

- **Clean membrane + clean water + phages:**

  viral removal by sole membrane

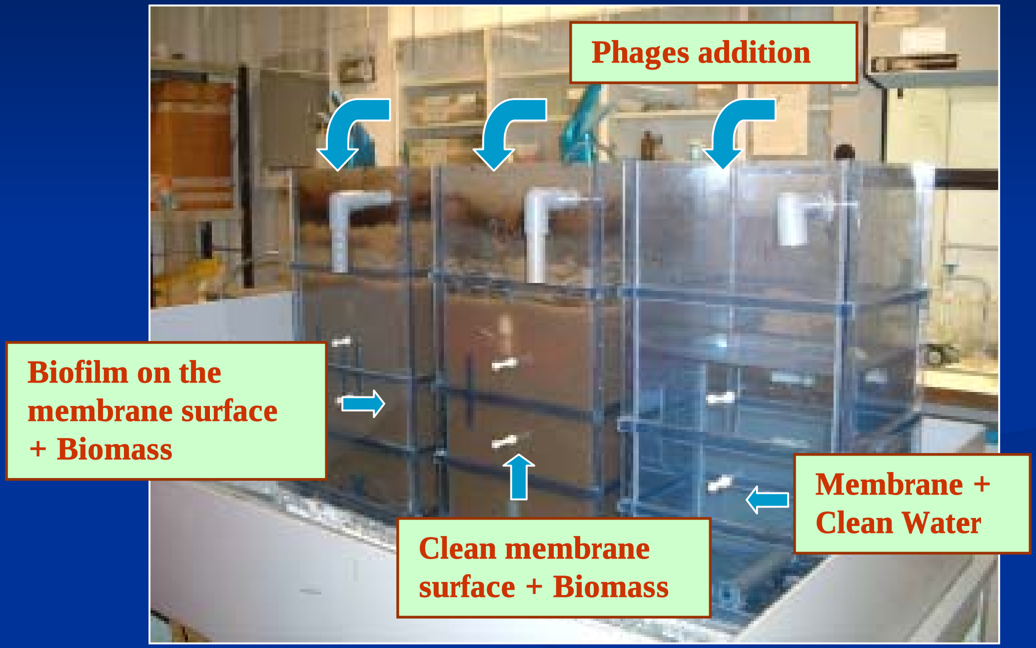
- **Clean membrane + biomass + phages:**

  - Short-term operation: viral removal by membrane and biomass
  - Long-term viral removal by membrane, biomass and biofilm

- The membrane was cleaned before the start of each cycle of operation

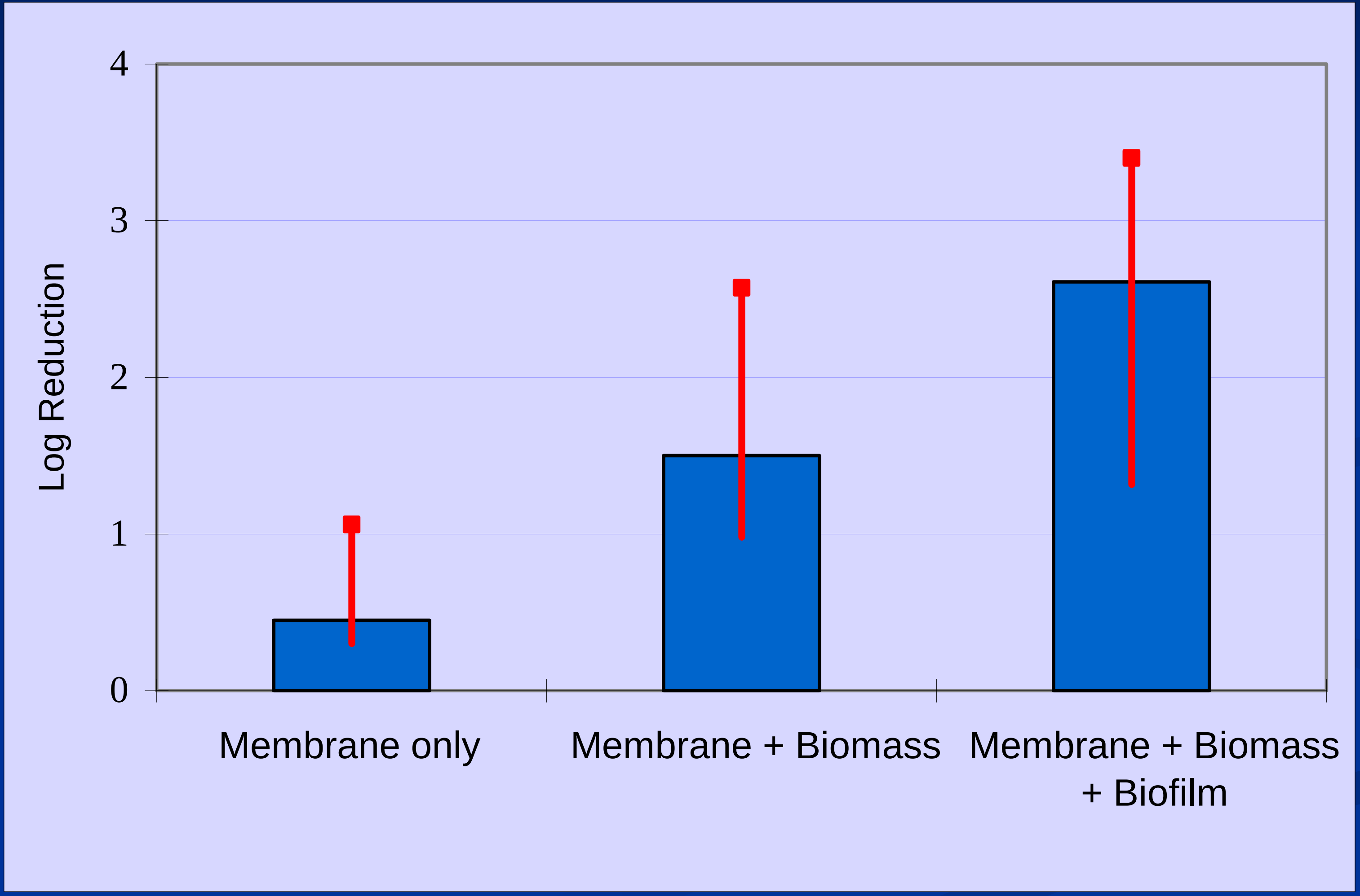
Bench-Scale MBR

- Reactor volume: 19 L
- Hydraulic capacity: 30~60 L/day
- Hydraulic Retention Time: 6~12hr
- MLSS: 6000 ~ 10,000 mg/L



- Feeding with synthetic water (without SS)
- Sampling of mixed liquor and permeate
- Air bubbling and 13 min on/2 min off intermittent suction for fouling control

Virus Removal under Different Operations



Results

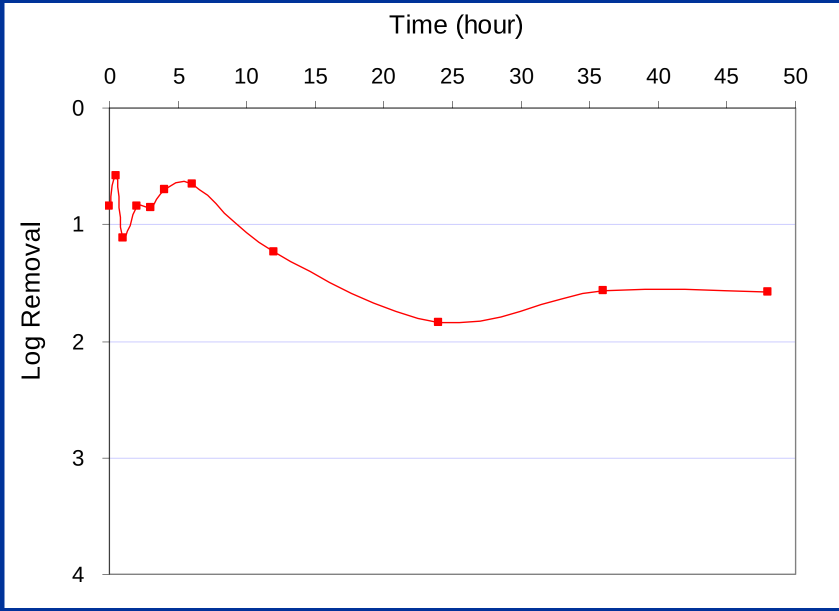
- Sole membrane only contributed to an average of 65% (0.45-log) MS-2 coliphage removal. This was obvious as the membrane pore size was much larger than the coliphage size.
- With the presence of biomass, phage removal got improved to 1.5-log reduction on average. The phages in this case are believed to attach on the biomass flocs and then get rejected by the filtration.
- With the presence of both the biomass and one month-grown biofilm on the membrane surface, the virus removal reached to 2.6-log on average. This indicated the importance of biofilm on viral rejection by the MBR.

Time-Dependent MS-2 Removal

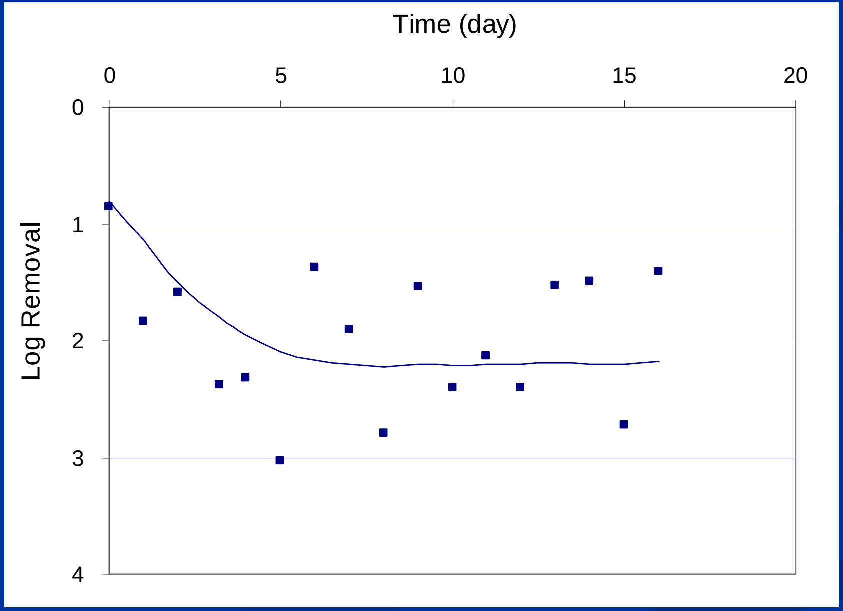
Operating conditions:

MLSS = 8000 mg/L

Initial flux = 0.25 $m^3/m^2/day$

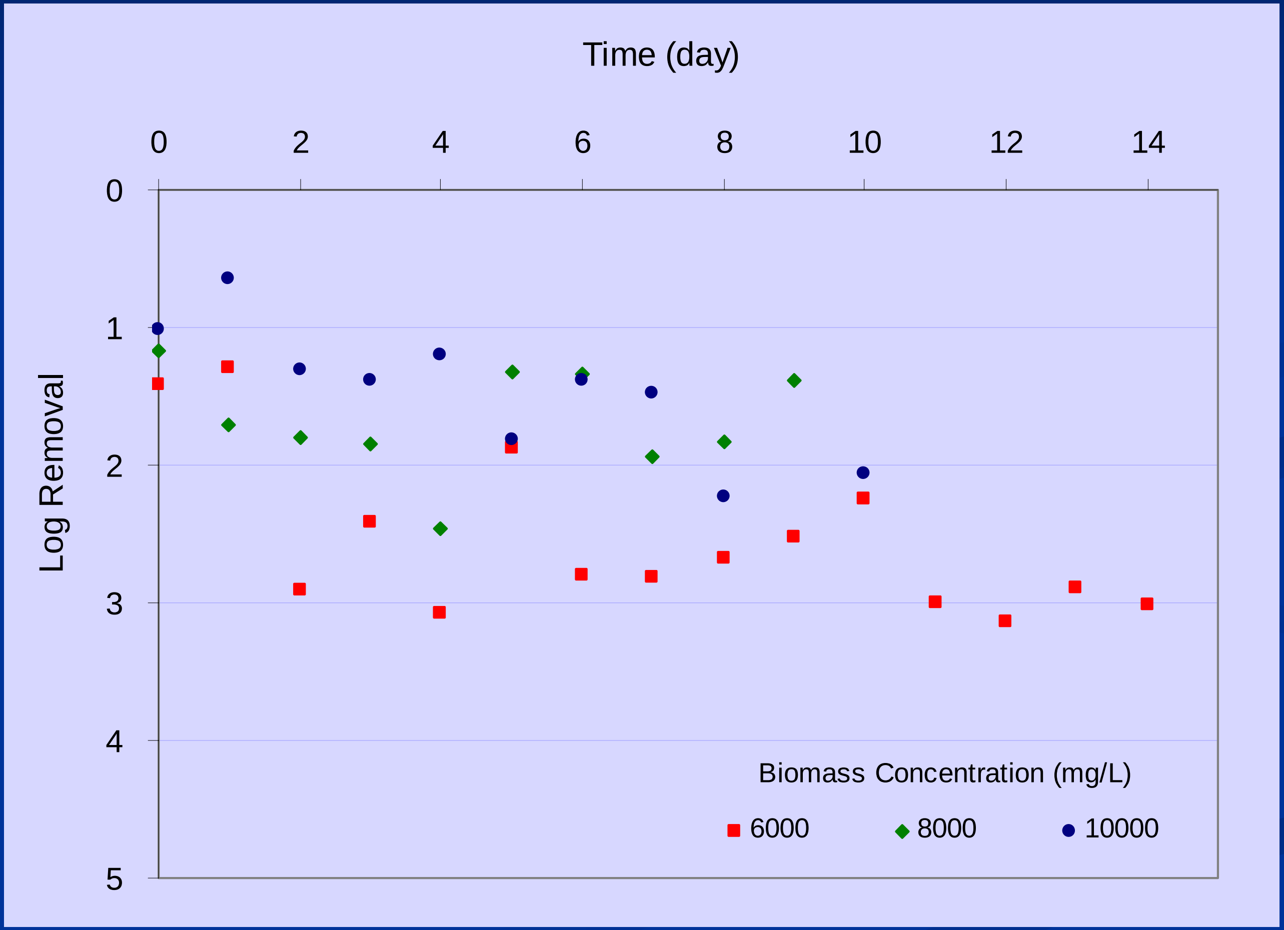


Short-term MS-2 removal

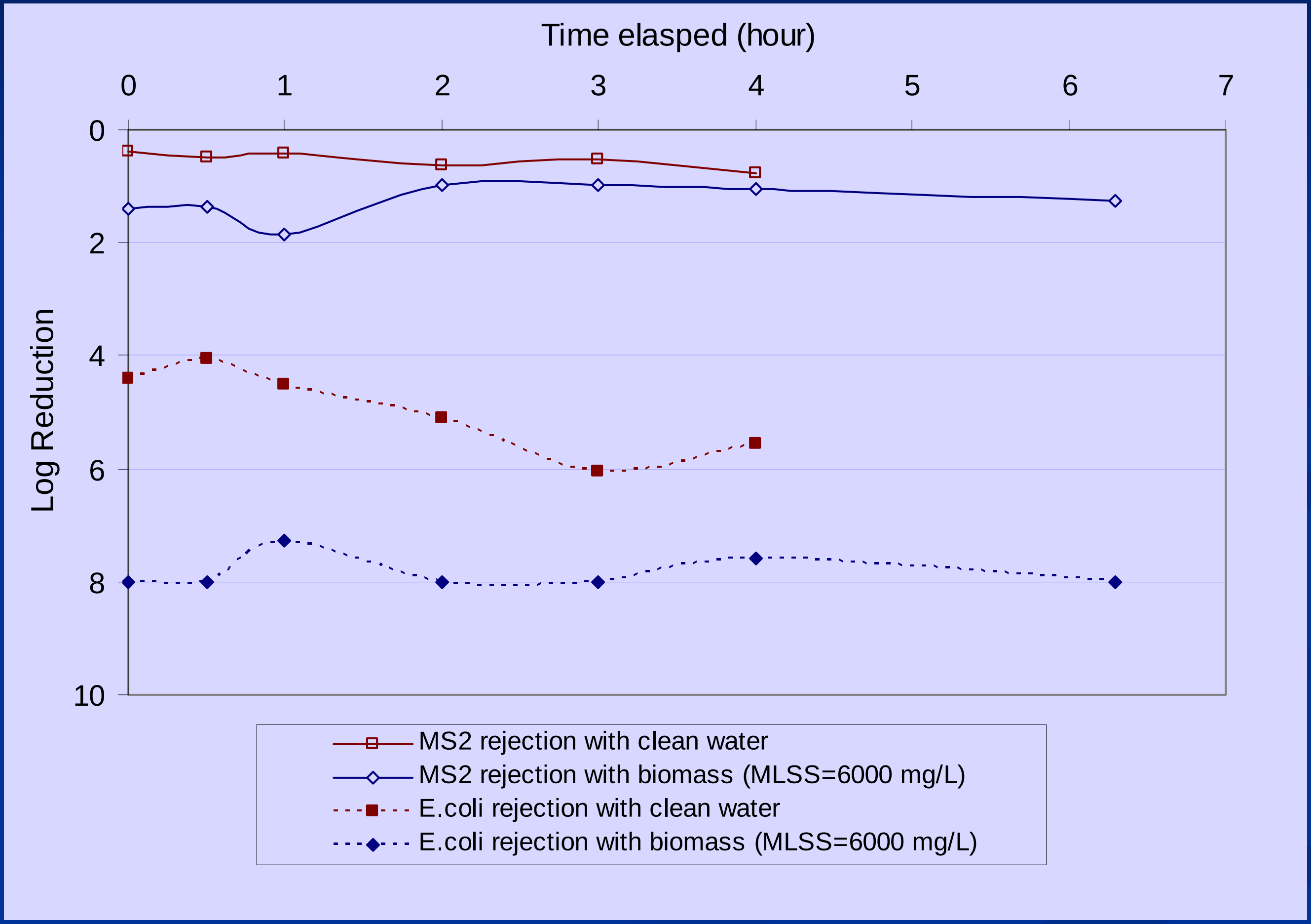


Long-term MS-2 removal

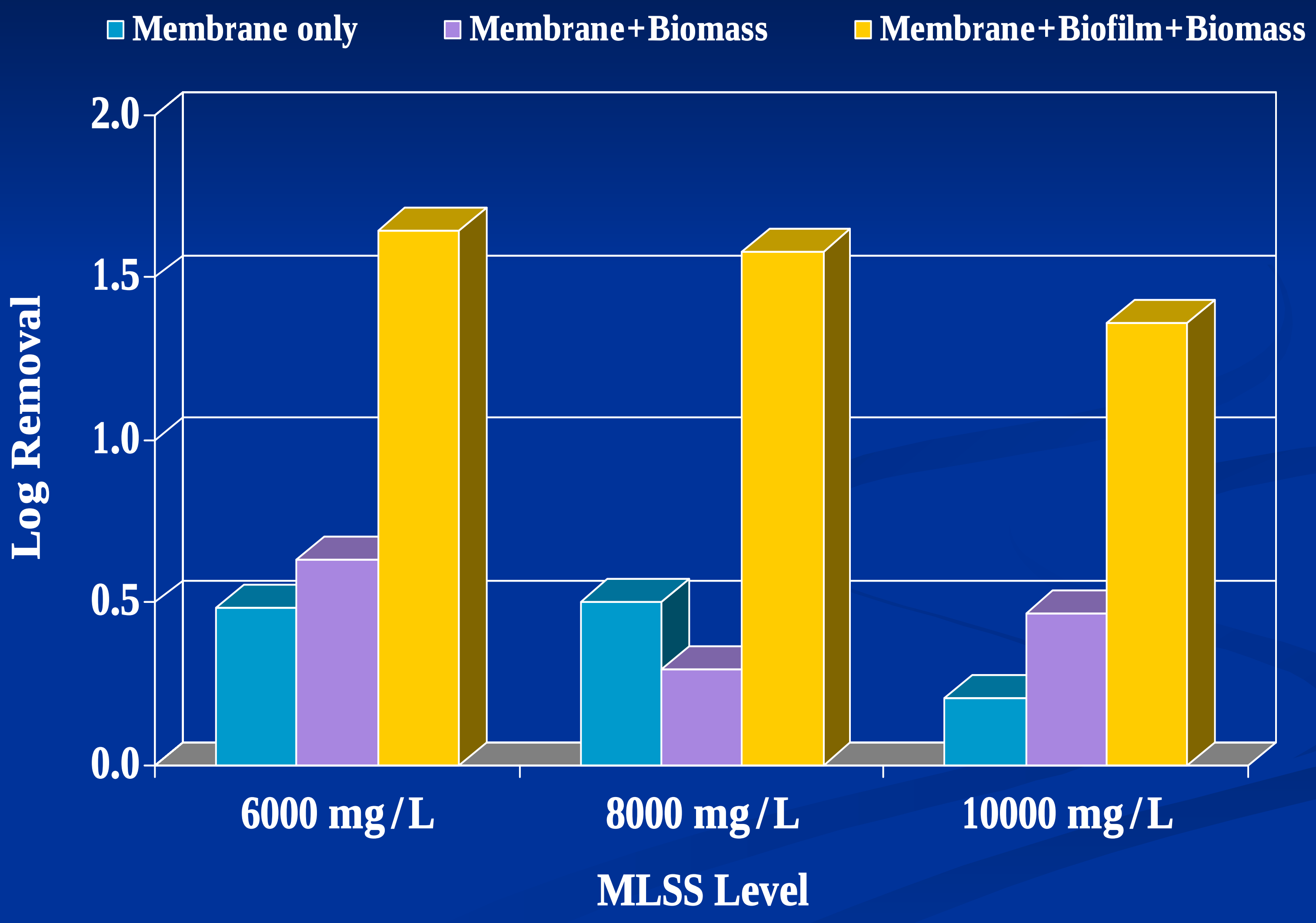
Effect of MLSS Level on Long-Term Virus Removal



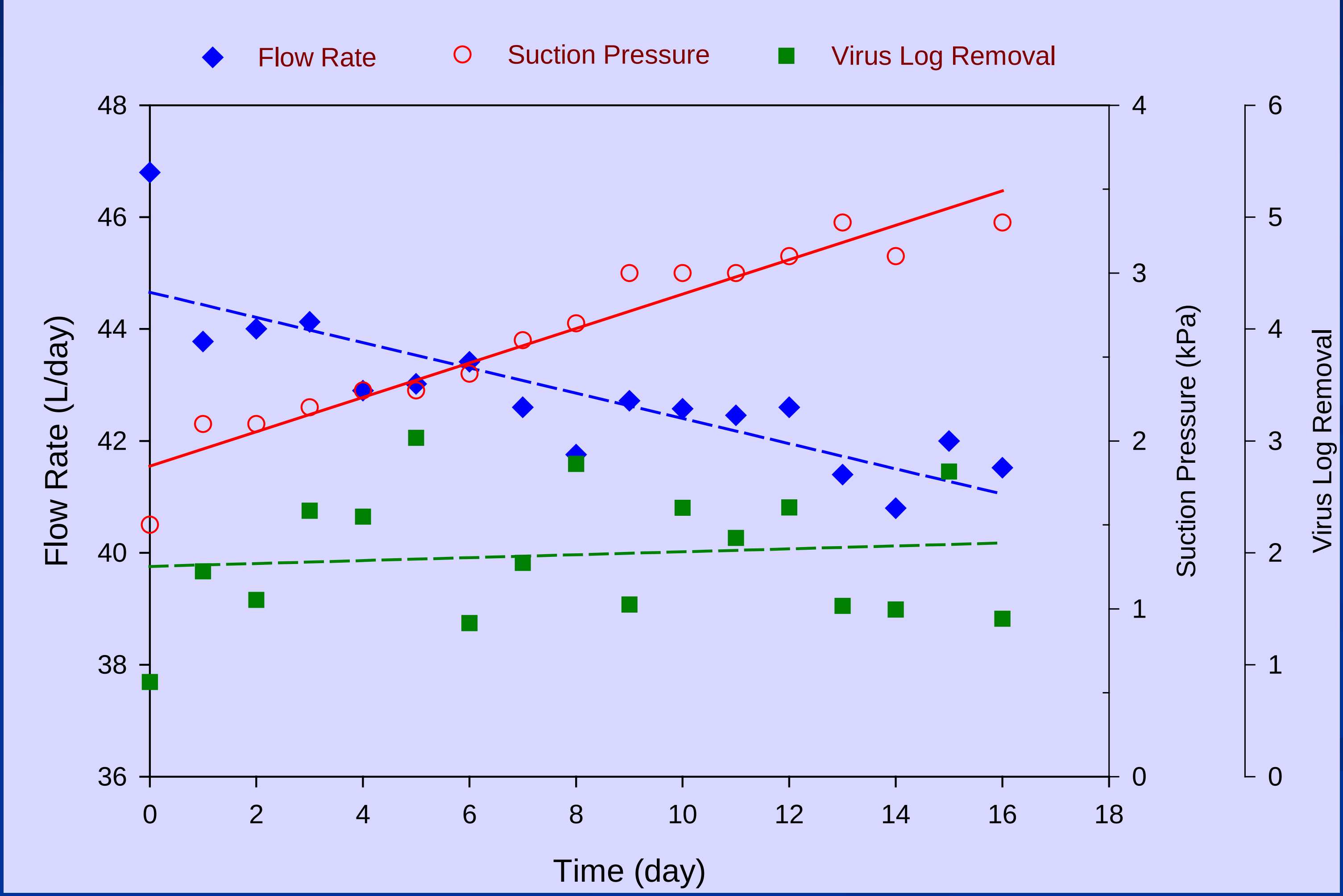
Variations in Microbial Removal



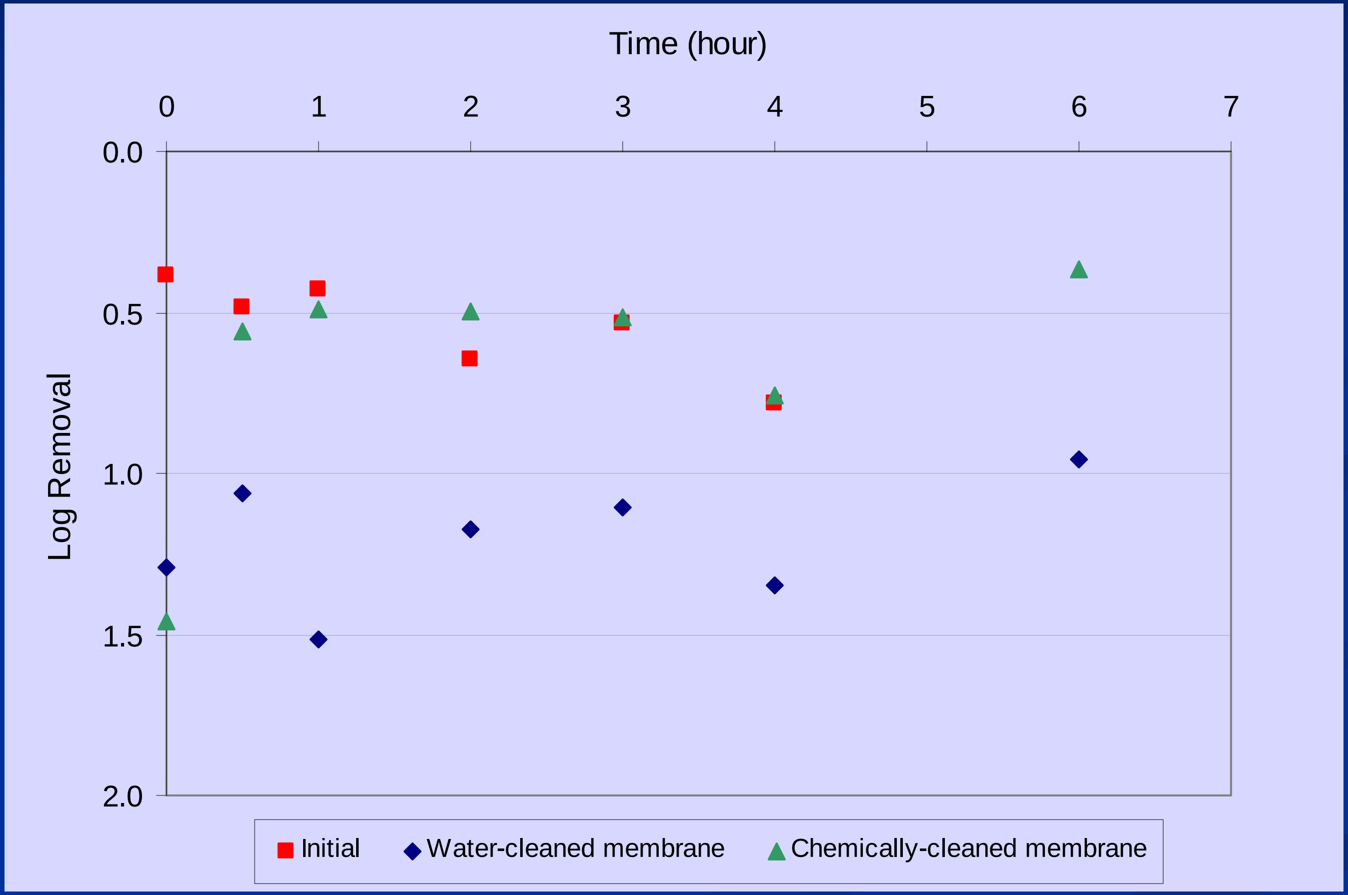
Effects of MLSS levels



Relation of Flux/Suction Pressure on Phage Removal



Effects of Membrane Cleaning



Summary

- Factors affecting virus removal:
  - Presence/absence of biomass & biofilm
  - MLSS concentrations
  - Size and surface properties of organisms
- Contribution of virus removal from the components:

Membrane only	< 0.5-log (68%)
Membrane + Biomass	~ 0.5-log
Membrane + Biofilm + Biomass	~ 1.5-log (97%)

- Biofilm plays the most important role in removing viruses, but it takes time to develop.
- MLSS of 6000 mg/L gives slightly higher removal among the three MLSS levels (6000, 8000, and 10000 mg/L).
- E. coli may not a good indicator for an MBR system, since it is too big in size and can be easily associated with sludge flocs.

Thank You for Your Attention