Future of Membrane Technology in Worldwide Sanitation

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This Presentation

- **Premise**
  - Membranes-based processes are the best available technologies for wastewater treatment and reuse
    - MF/UF for tertiary filtration or MBR
    - RO for desalination or polishing

- **Objective**
  Establish gaps in current knowledge / products / practices

- **Approach**
  Identify key issues on selected topics

Selected Topics

1) Water reuse versus seawater desalination
2) Tertiary filtration versus membrane bioreactor
3) Pressurized versus immersed membranes
4) MF/UF and RO pre-treatment
5) Flux and fouling
6) MBR pre-treatment
7) The use of air with membranes
8) Handling residuals

1) Water Reuse vs Seawater Desalination

- Sewage is the only abundant source of water present wherever there are people…
- For environmental sustainability, sewage needs to be treated biologically for discharge
- The incremental cost for reuse is a fraction of the cost of seawater desalination
- The main adoption barrier is not technical, but public acceptability…

Water Reuse vs Seawater Desalination

Water Reuse

Seawater Desalination

Process Design Conditions for the Comparison of Water Reuse and Desalination

Unit process	Parameter	Units	Water Reuse	Desalination
Coagulation	$FeCl_3$ dose	mg/L	No	5
Pretreatment			MBR or CAS-TF effluent	Multi media filtration
Anti-scalant addition	Dose	mg/L	2	5
Reverse Osmosis	Stages	Number	1	2
	Recovery	%	>80	<50
	Flux	$L/m^2/h$	20	14
	Feed pressure	bar	13.6	54

Costs of Producing Water from Secondary Effluent and from Seawater

Component	Units	A: from CAS effluent	B: from seawater	Ratio (B/A)
Capital costs				
Infrastructure & pretreatment	$\$/m^3/d$	161	320	1.99
RO	$\$/m^3/d$	321	624	1.94
Total	$\$/m^3/d$	**482**	**944**	**1.96**
Total Life cycle costs				
Capital	$\$/m^3$	0.07	0.24	3.43
O&M	$\$/m^3$	0.21	0.38	1.81
Total	$\$/m^3$	**0.28**	**0.62**	**2.21**

2) Tertiary Filtration of CAS versus MBR

Tertiary Filtration

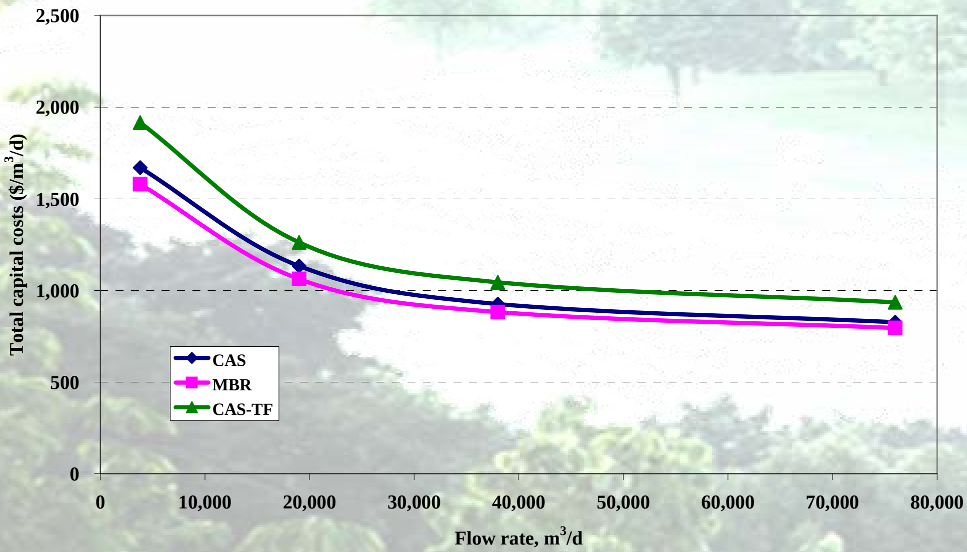
- Conventional activated sludge plant exists
- Discharge requirements are met
- WW flow is highly variable
- Reused water needs are seasonal
- Reused water flow rate is a small portion of the total flow rate
- Flux limited by fouling

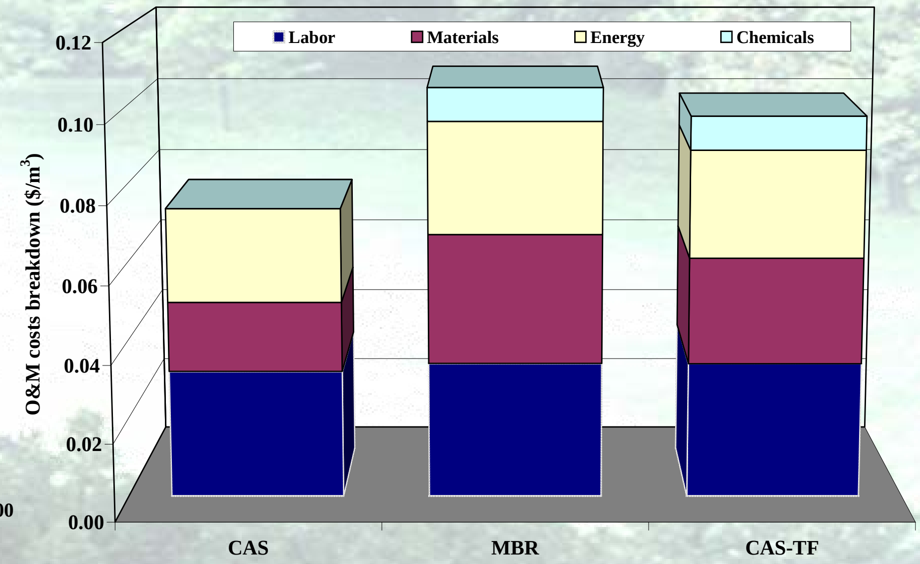
Membrane Bioreactor

- New plant
- Stringent discharge requirements
- Low peaking factors
- Large fraction of volume treated is reused
- Flux limited by solids handling
- Pre-treatment critical to protect the membranes

Cost Comparison of CAS, Tertiary Filtration and MBR

- Capital costs of MBR are lower
- O&M cost of MBR are larger
- Overall, there is a 10-15% premium over CAS for adding a membrane step





3) Pressurized versus Immersed Membranes

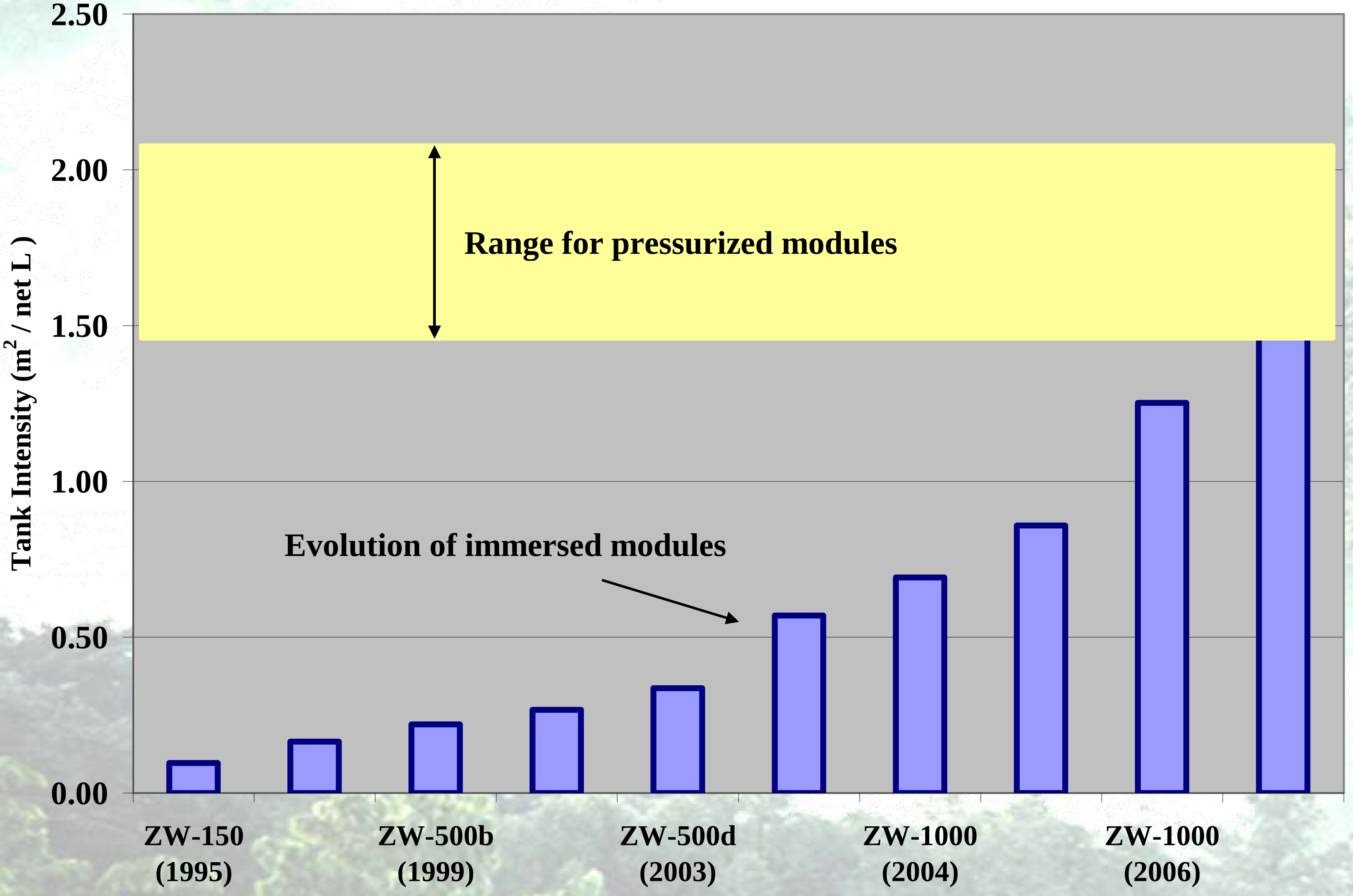
Pressurized

- I/O or O/I; cost penalty (≈40%) for I/O difficult to overcome
- Higher TMP possible is a benefit for low fouling water
- Air essential for cleaning in O/I configuration
- Cost benefits for smaller systems

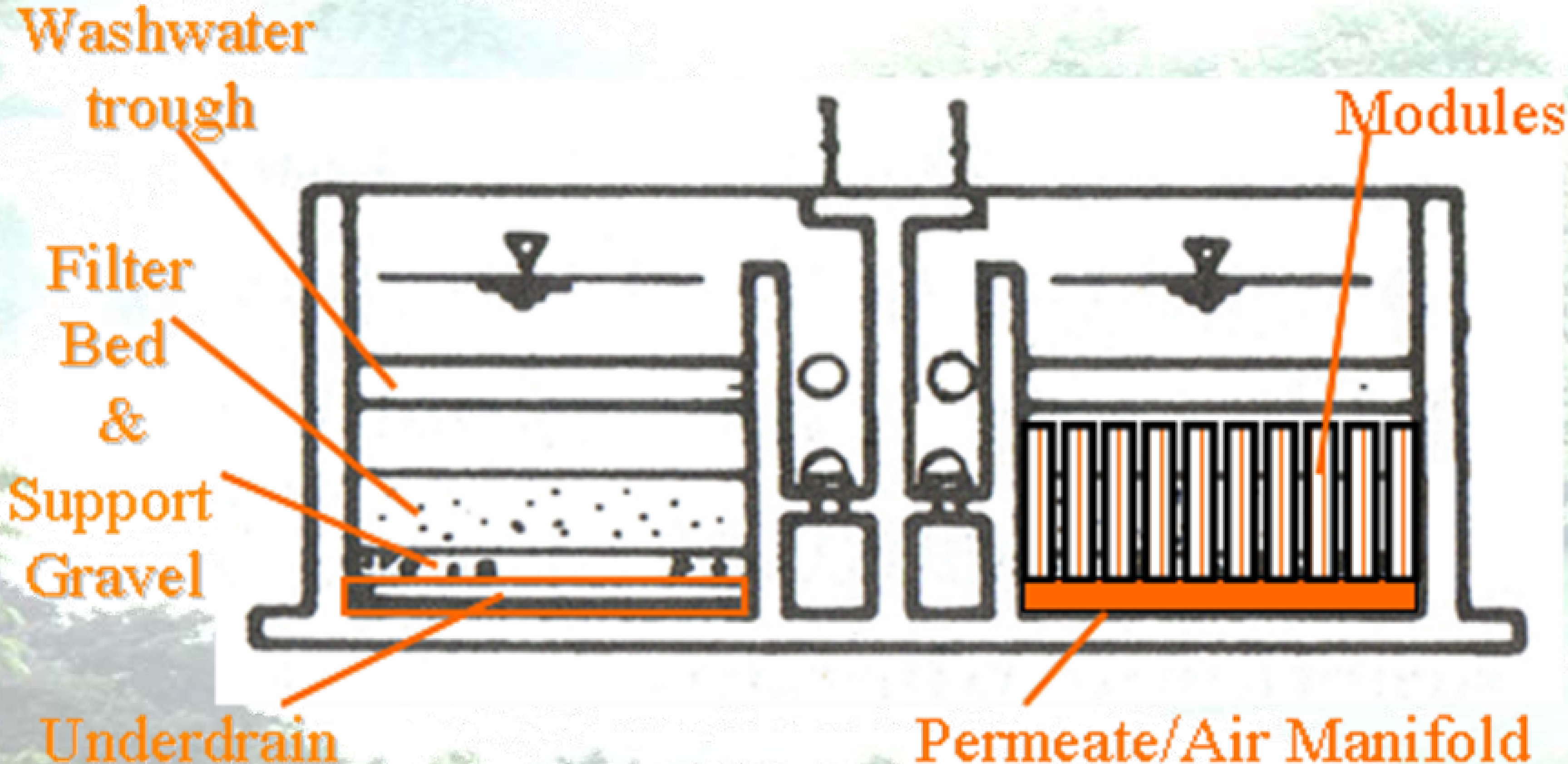
Immersed

- Only O/I
- Lower TMP and flux are benefits for high fouling water
- Packing density penalty disappearing…
- Easier scale-up makes it better for large scale systems

Evolution of Immersed Membranes



Can Immersed Membranes be Used in a Simple Sand Filter Retrofit?



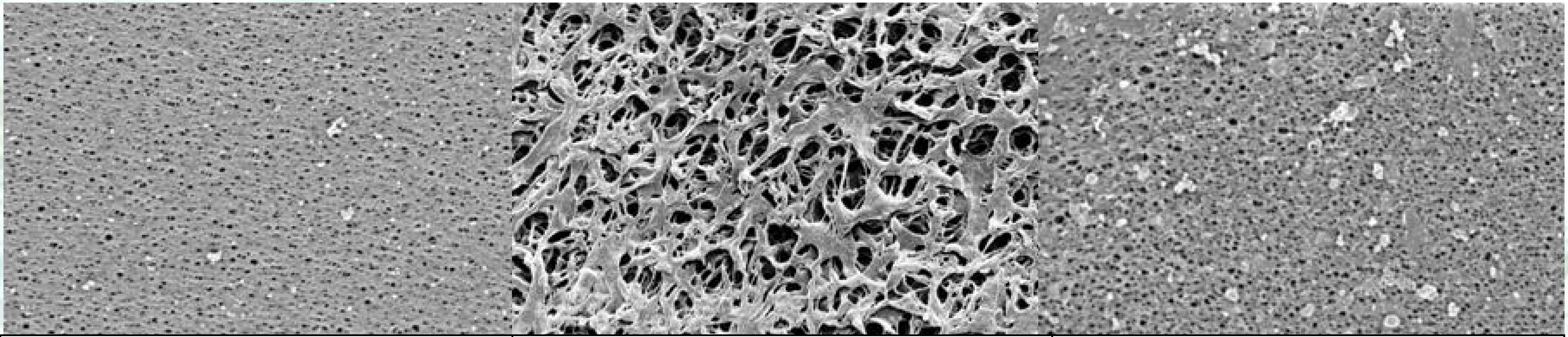
4) MF/UF as RO Pre-treatment

- Best pre-treatment for particles and colloids
- May increase the rate of organic fouling when compared to coagulation / filtration
- Does little to protect against bio-fouling or scaling
- Does MF/UF pre-treatment increase the risk of RO membrane damage by chlorine?
- Can RO modules / systems be optimized for use with MF/UF pre-treatment?
- How to best integrate an interrupted process (MF/UF) with a continuous process (RO)?

5) Balance between Flux and Fouling

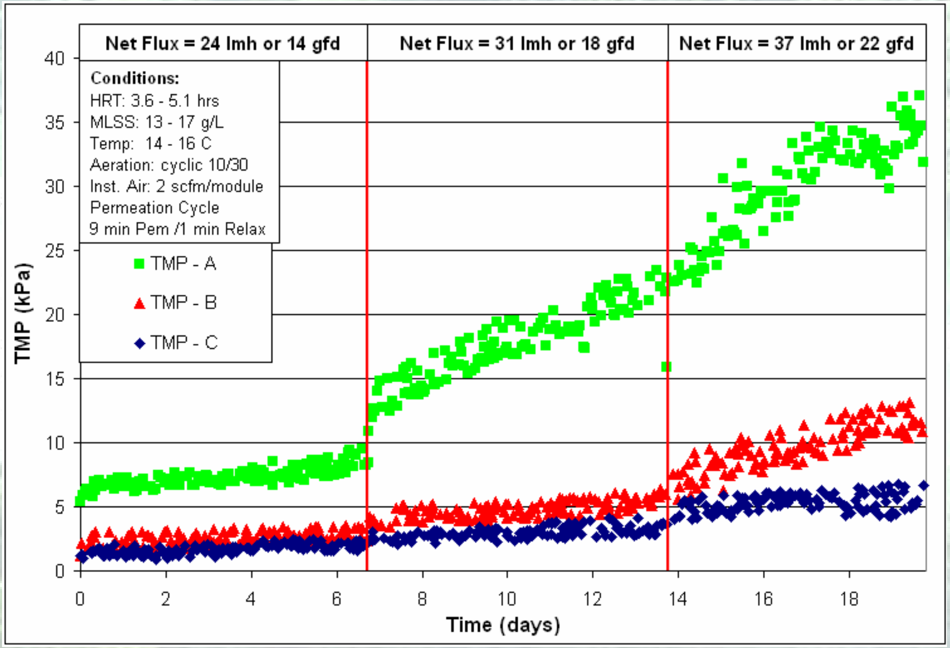
- Current project evaluation criteria favour higher flux (are the consequences of frequent cleaning properly evaluated?)
- Membranes with a large number of small pores are better…
- Biggest manufacturers challenge is to develop permanently hydrophilic membranes
- Fouling in seawater is not well understood
- What is the best approach to improve the filterability of MBR sludge?

Importance of Membrane Morphology



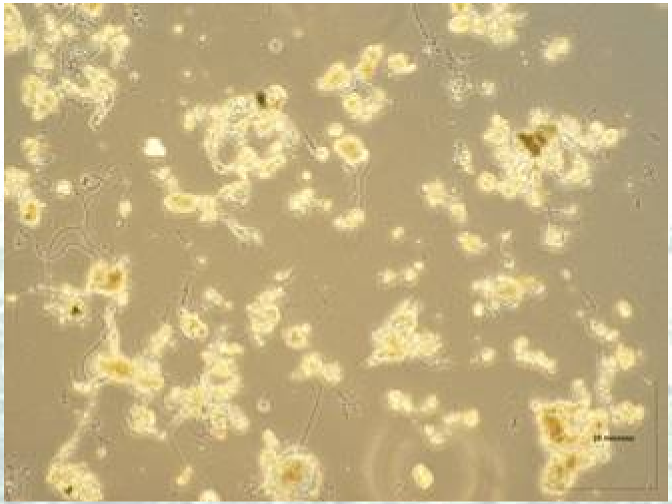
A (100kx): 0.04 μm 300 Lmh/bar	B (20kx): 0.4 μm 1500 Lmh/bar	C (100kx): 0.04 μm 1000 Lmh/bar

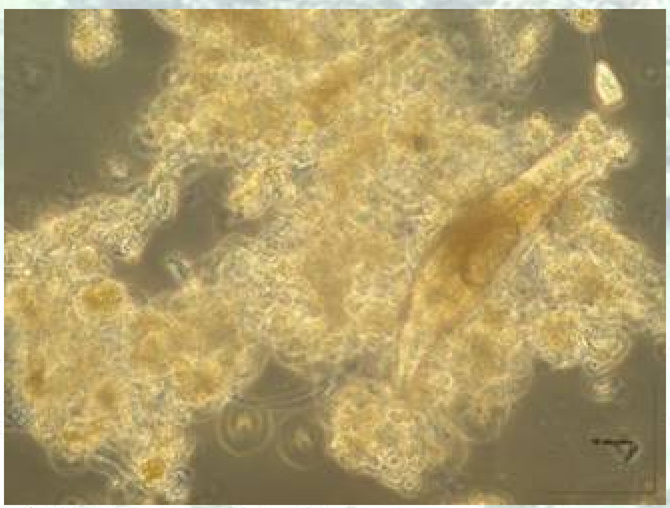
Large number of small pores allows high permeability and prevents deep membrane fouling



How to Enhance MBR Sludge Filterability

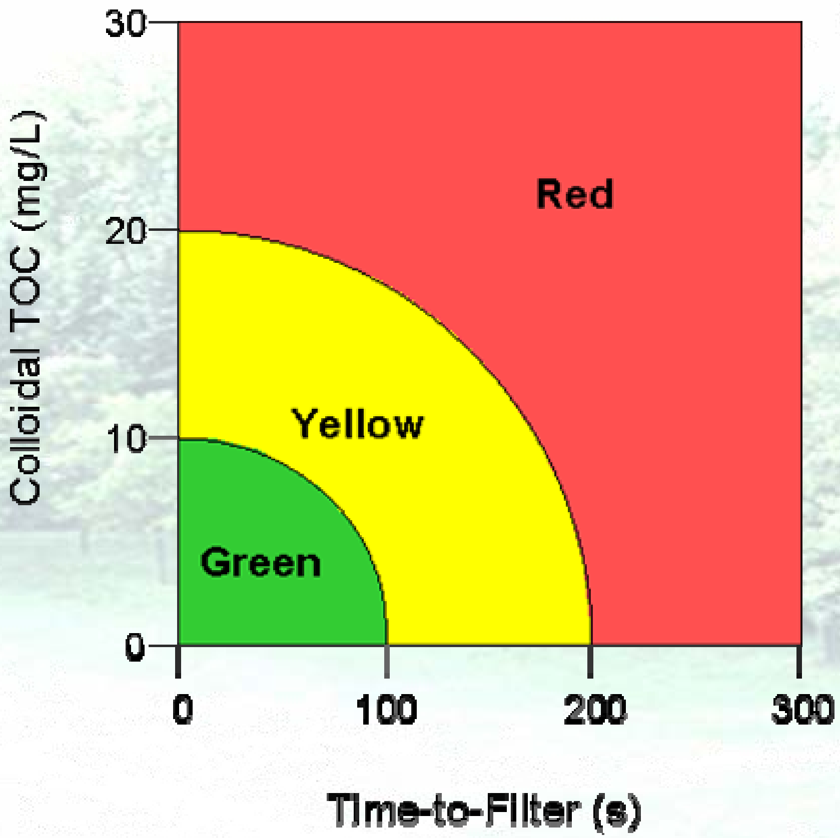
1. Ensure complete nitrification (SRT > 12-d)
2. Avoid extra long SRT that results in entrapment of colloids in the ML
3. Maintain DO > 1-mg/L in the membrane tank
4. Provide minimum HRT of 2-hours between feed addition point and membranes
5. Use low shear RAS pumps
6. Avoid sudden changes in environmental conditions (pH, loading, etc.)





Sludge Filterability

Mixed Liquor Property	Significance	Method
Hydraulic permeability of the cake layer formed from large flocs	Dominates in low shear membrane filtration system	Modified Time-to-Filter
Pore-plugging potential of interstitial colloidal particles	Dominates in high shear membrane filtration system	Colloidal TOC



6) MBR Pre-treatment

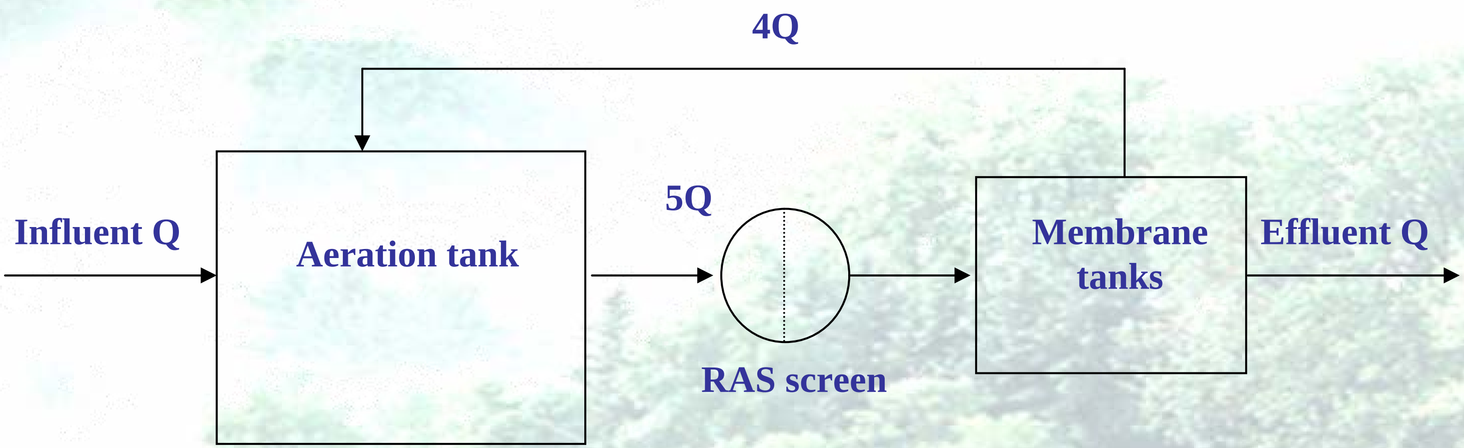
- Sewage contains 10-20 mg/L of trash that can be concentrated by a factor of 50-100 in a MBR (SRT/HRT)
- Impacts of poor pretreatment include reduction in hydraulic capacity, degradation of effluent quality, increase in O&M costs, reduction in membrane life
- Designing modules to handle trash leads to sub-optimal performance…
- Fine head-works screening represents only 3% of the total investment cost for a MBR
- Mixed liquor screening is an option to fully protect the membranes and eliminate the generation screenings as a separate waste stream

Importance of MBR Pretreatment…

Hollow Fibres

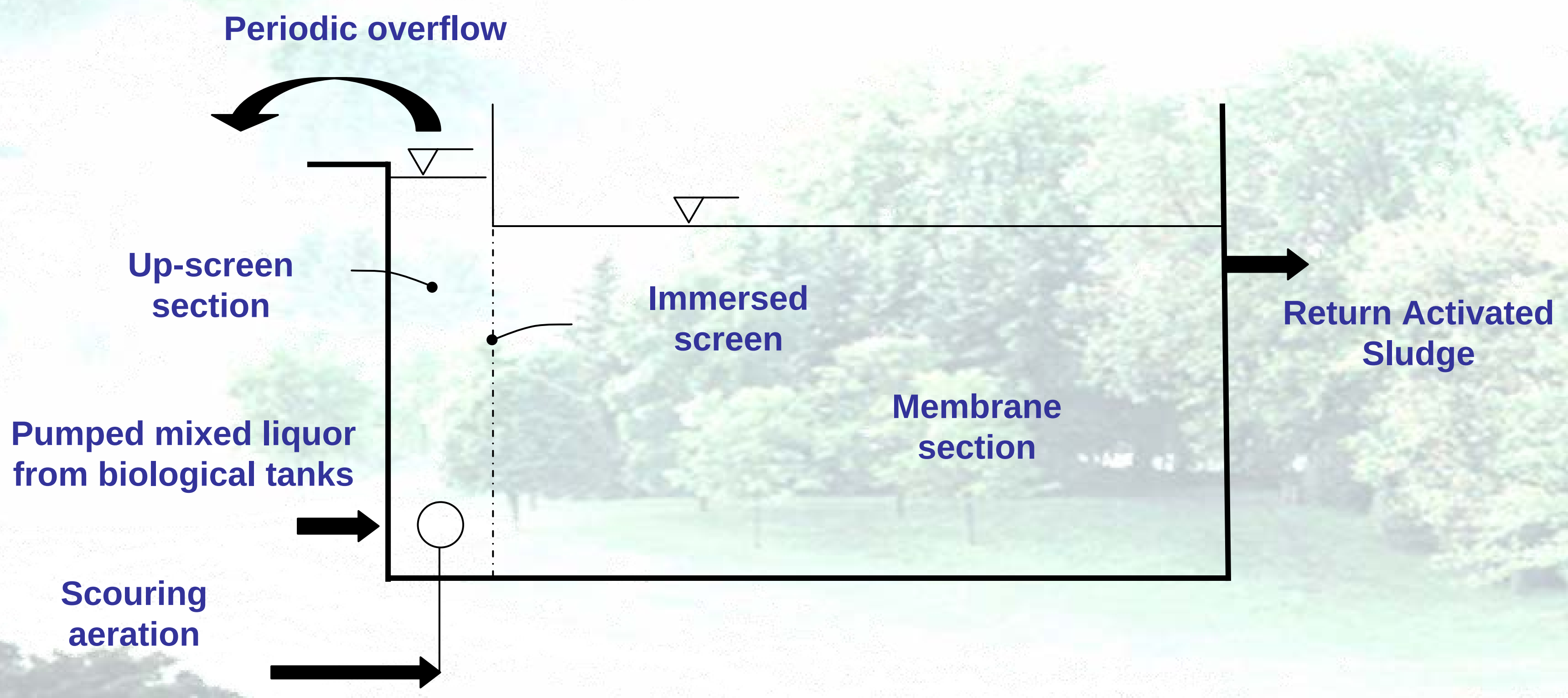
Flat Sheet

Full RAS Flow Screening



- Only option to positively protect the membranes from trash in the feed and contamination downstream of head-works
- Possibility to relax head-works screening requirements
- Trash remain in the aeration tank and can be extracted with the waste activated sludge

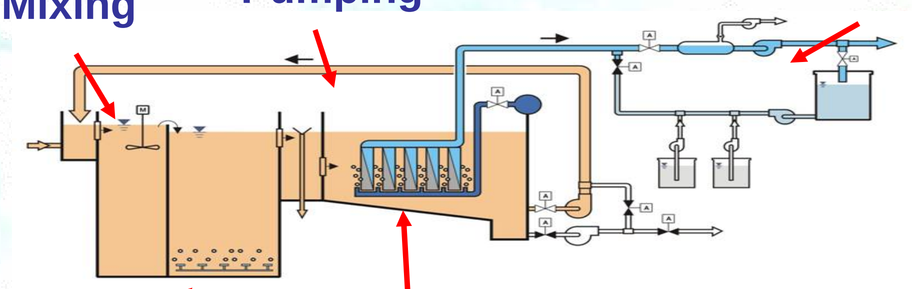
Immersed Screen Concept



7 The Use of Air for Scouring Membranes

- Essential process feature with O/I hollow fibres
- Used only as part of back-wash sequence in low solids applications
- Used “continuously” in MBR applications
- Cyclic aeration to improve scouring performance and reduce energy consumption
- Coarse bubbles needed for scouring efficiency
- Little contribution to oxygen transfer in MBR

MBR Energy Users
(with 10/10 membrane aeration)



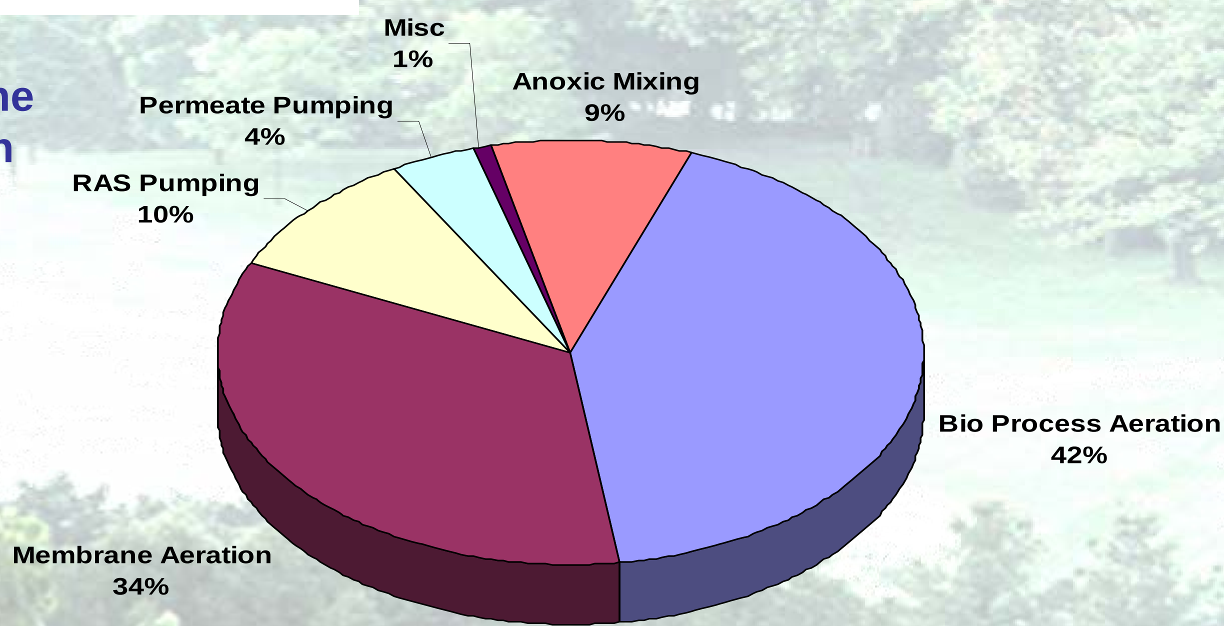
Anoxic Mixing

RAS Pumping

Permeate Pumping

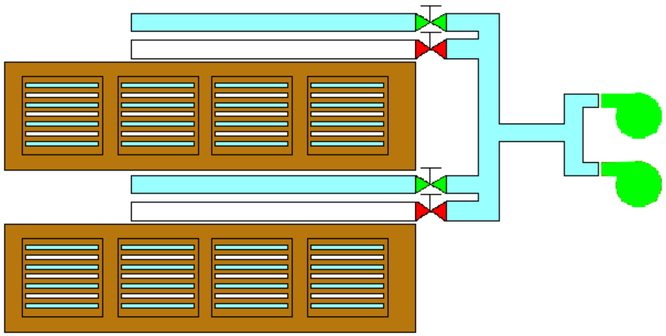
Biological Process Aeration

Membrane Aeration

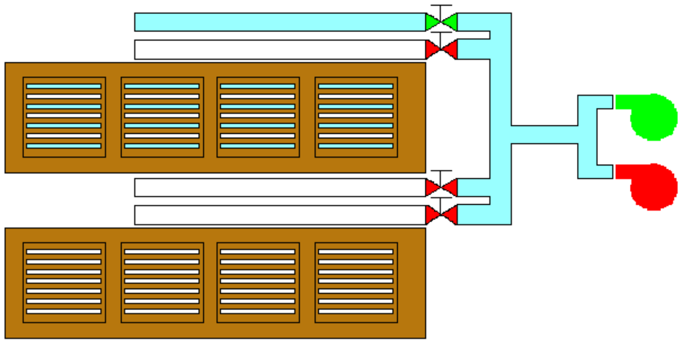


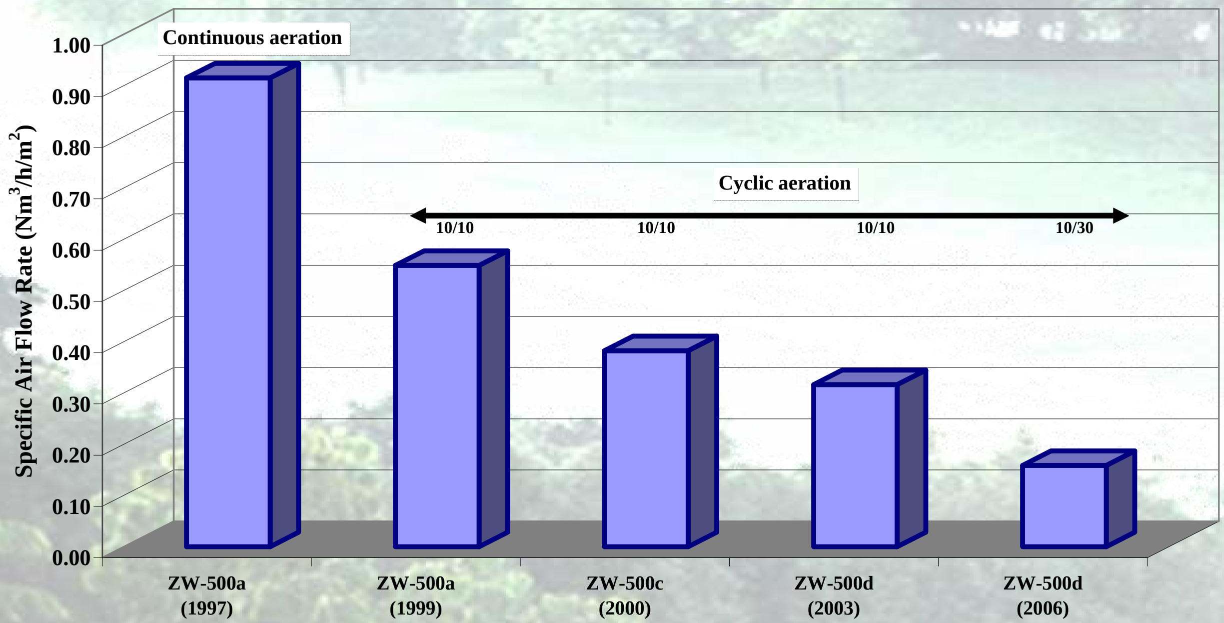
Cyclic Aeration

10s on / 10s off



10s on / 30s off

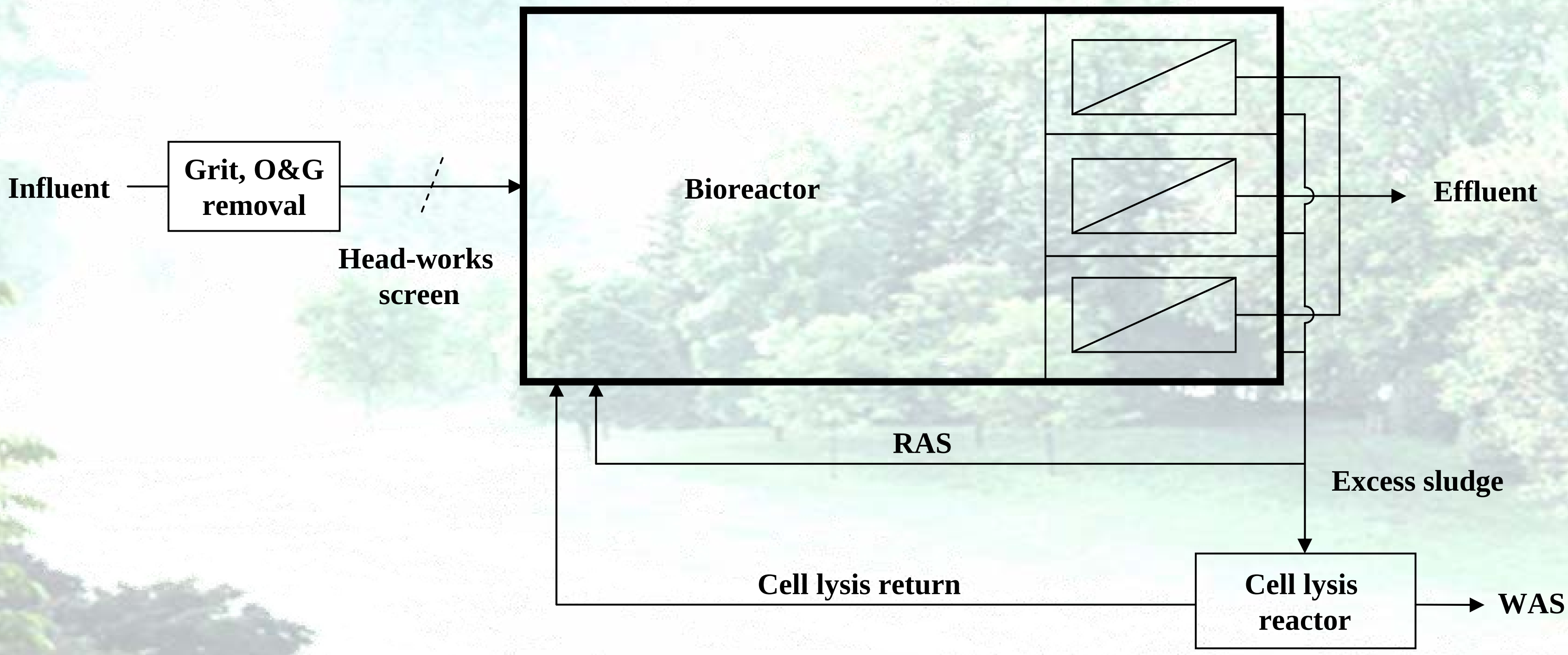




8) What to do with MBR residuals?

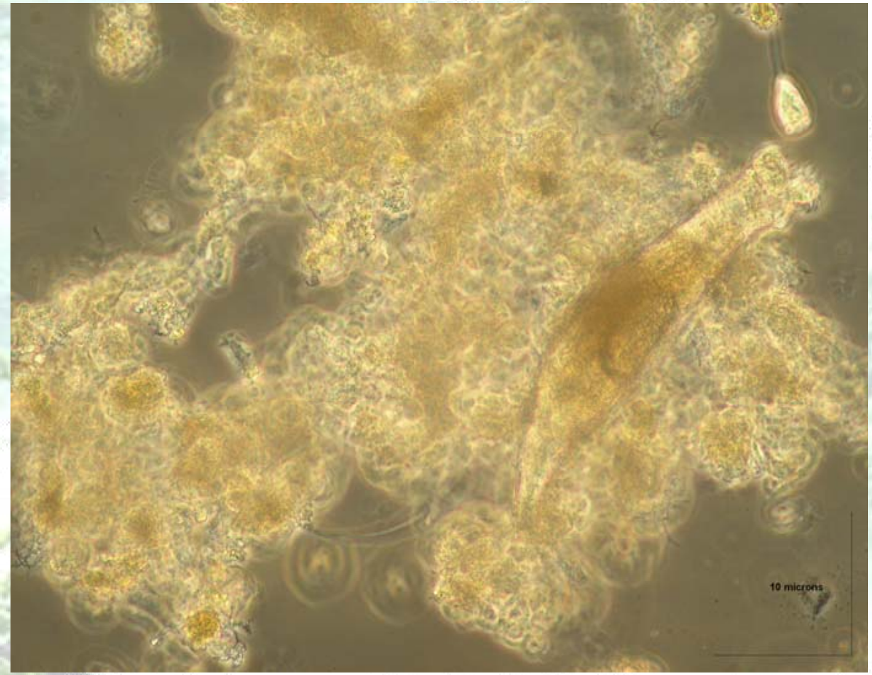
- Minimize their formation; is sludge reduction in the MBR feasible?
- Can low growing biomass be combined with MBR (attached growth, membrane-supported biofilm, aerobic granules)?
- An anaerobic MBR would offer low residuals with the potential of biogas production, but…

Sludge Reduction Process Flow Diagram



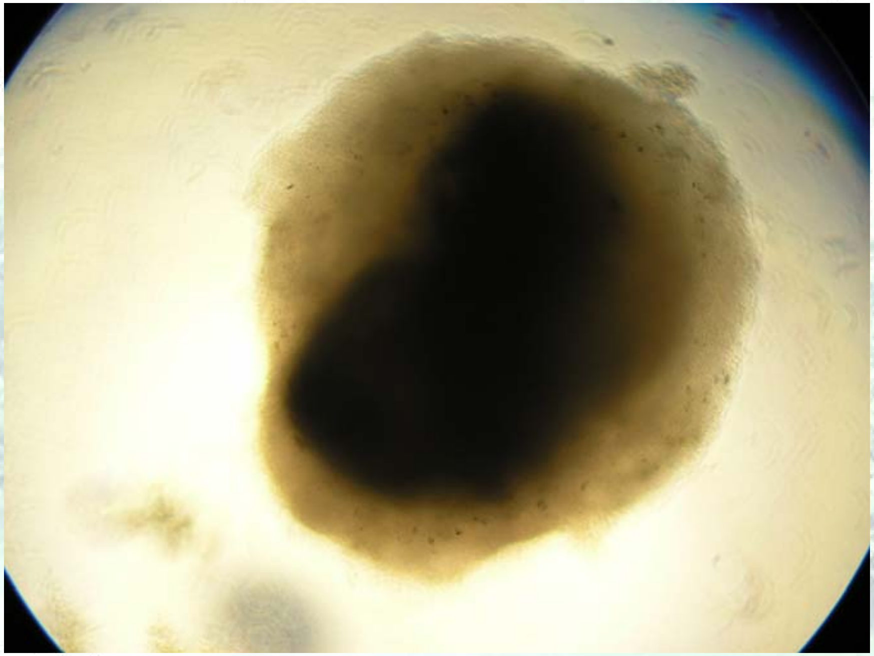
Light flocs versus Aerobic Granules

Light floc



Settling velocity = 1-3 m/h

Aerobic granule



Settling velocity = 30 to 70m/h

Membrane-Supported Bioreactor

Can fine hollow fibres be used for oxygen transfer and as a support for biomass?

Potential benefits:

- 4-5 fold reduction in aeration costs
- Low excess sludge
- Low suspended loading to final membrane separation step