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EXPERIMENTS IN AEROBIC WASTEWATER TREATMENT IN MEMBRANE BIOREACTORS

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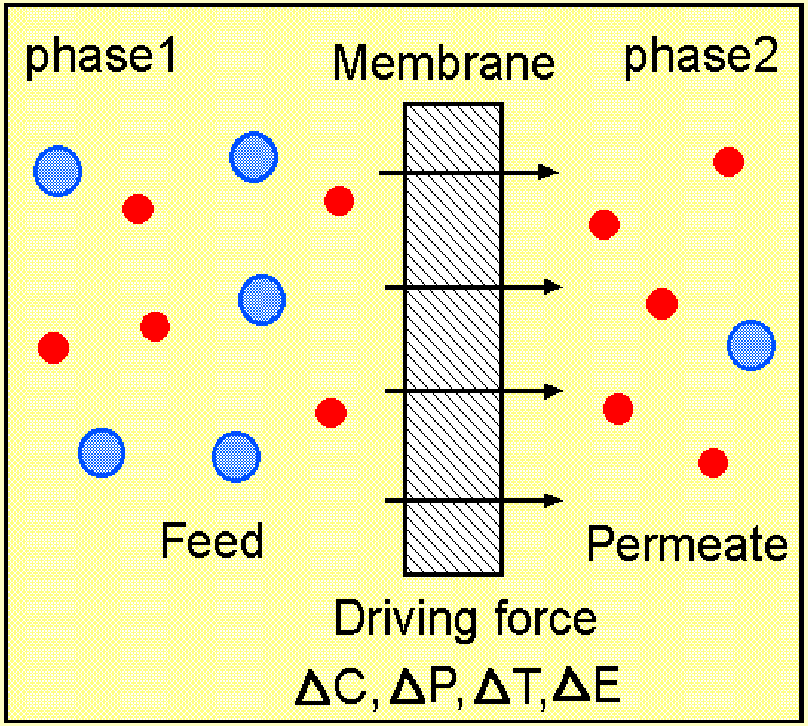
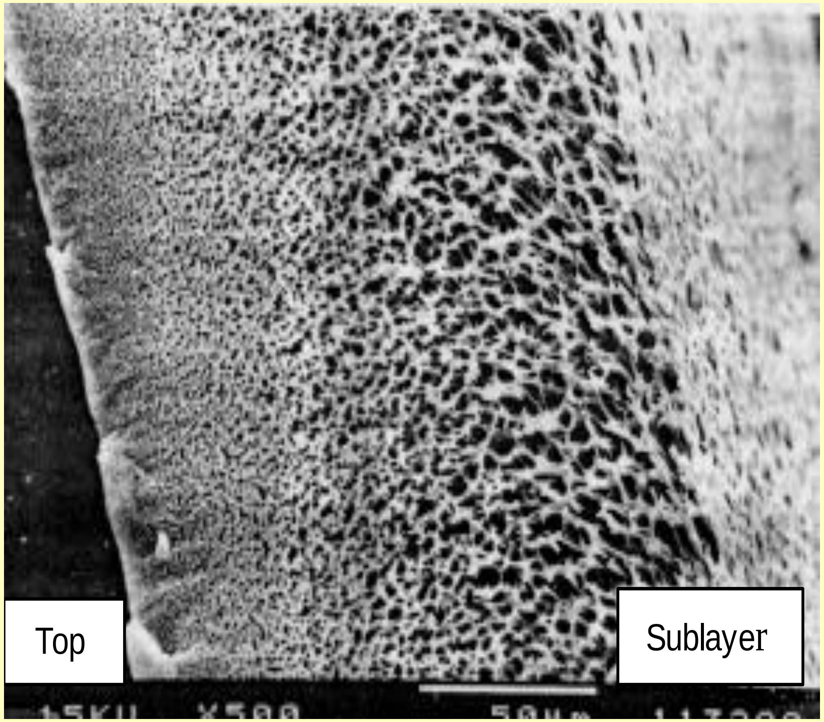
Definition of membrane

- **Membrane**
  - a selective barrier between two phases
  - transport one component more readily than others

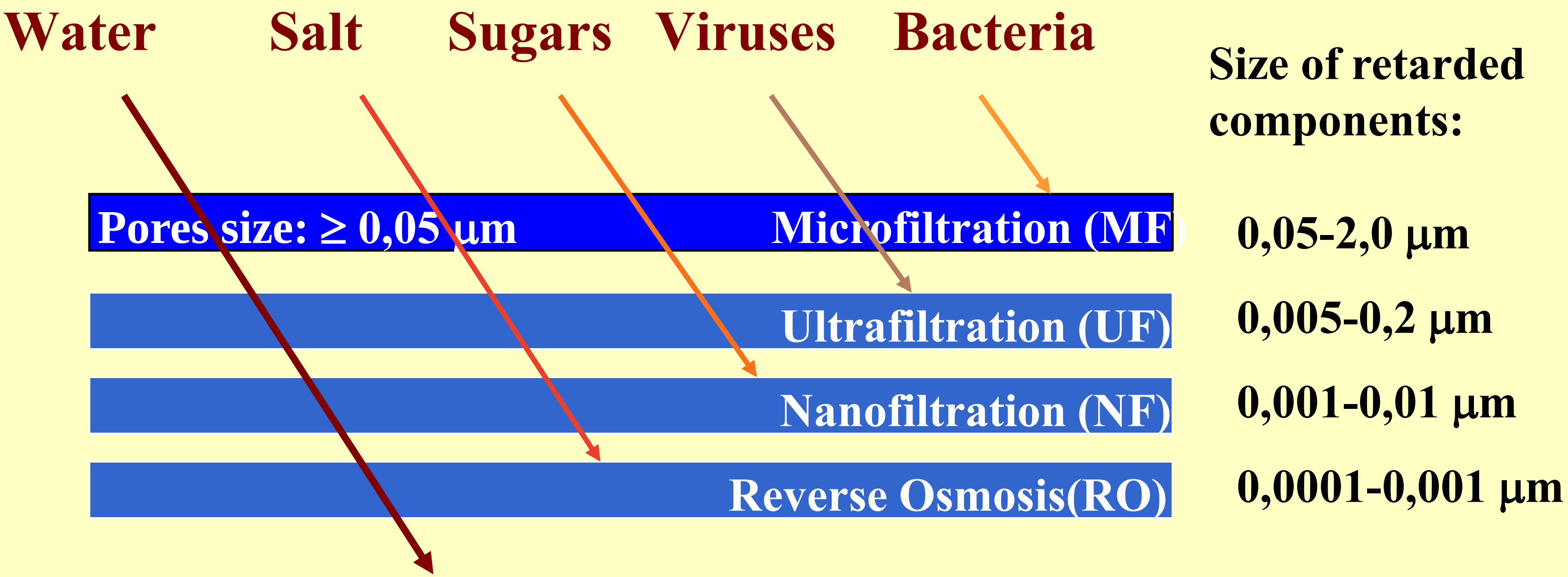


Two-phase system separated by a membrane



Cross-section of membrane

Membrane Filtration Processes



Membrane bioreactors: most often microfiltration

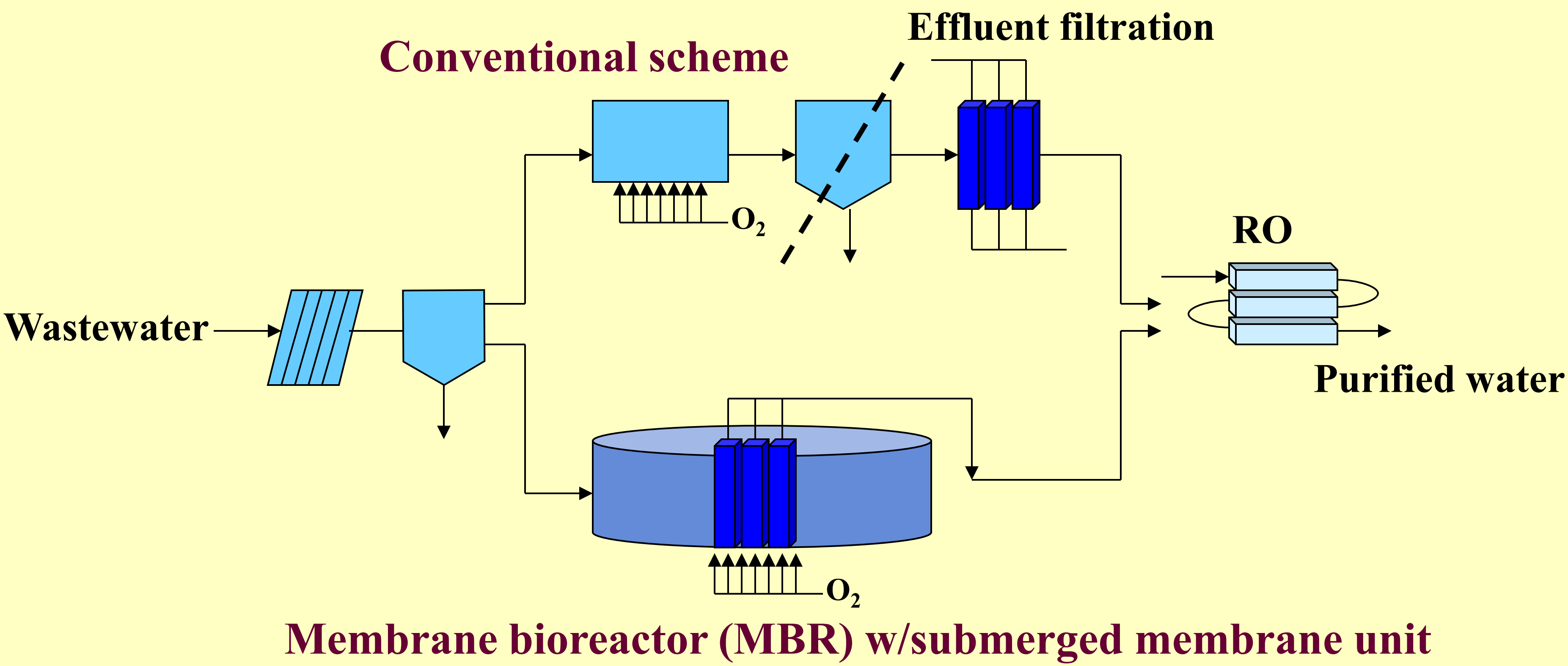
Membrane Bioreactors (MBRs)

- **combine membrane filtration with biological wastewater treatment**

- **most often replace the secondary sedimentation, providing a complete separation and retention of biomass**

= activated sludge reactor where the solid-liquid phase separation is done with the help of membrane

Membrane bioreactor & conventional treatment schemes



- **Two configurations:**
  - Downstream low-pressure membrane unit (replace the clarifier)
  - Submerged membrane unit
  - (Note: no direct comparison of the two has been found in the literature.)

Why Membrane Bioreactor?

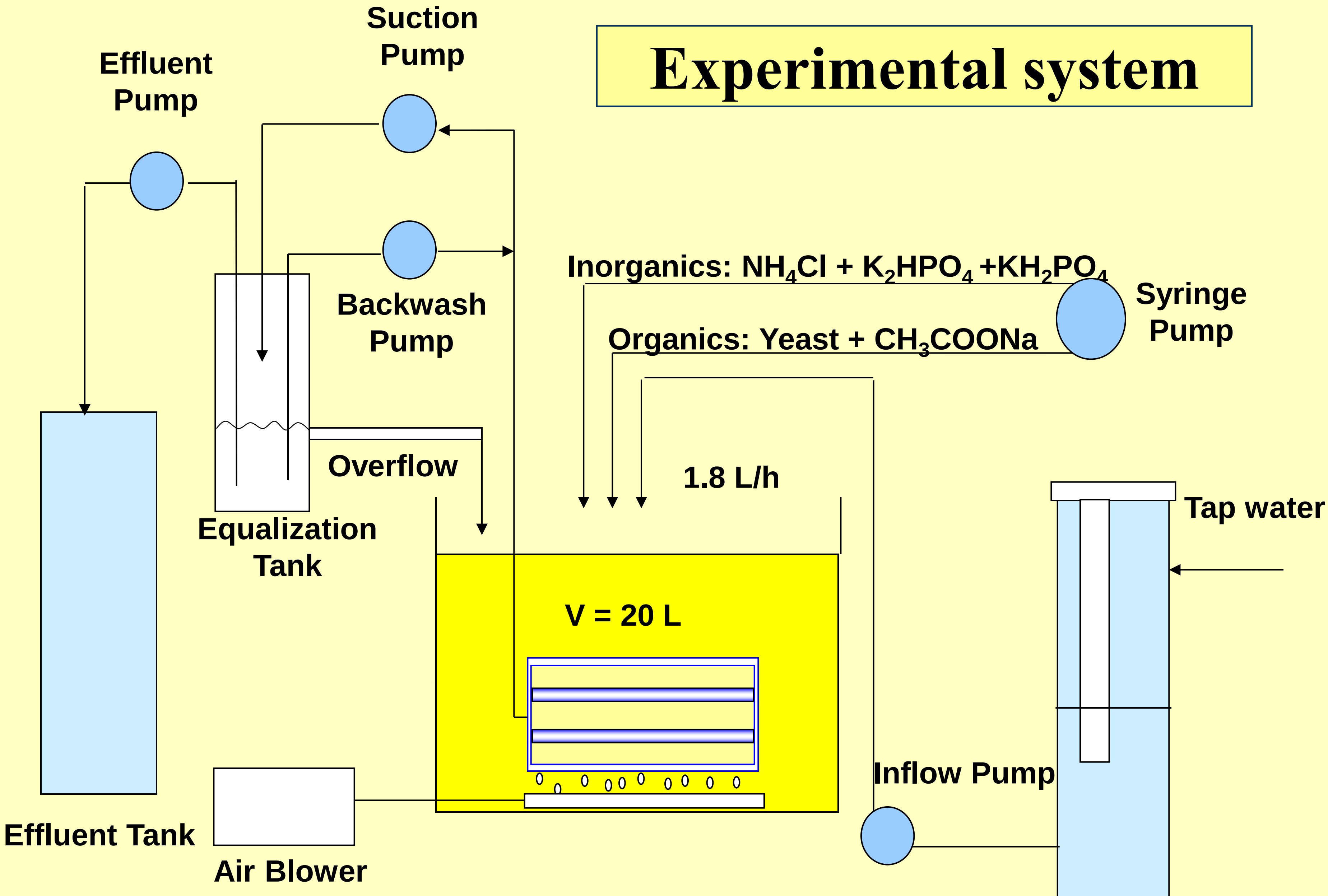
Advantage	Disadvantage
Small footprint (high biomass concentration)	Membrane fouling
Complete solids removal	Aeration limitations
High loading rate capability	Energy cost
Effluent disinfection	
Low sludge production (0.23 kgSS/kgCOD removed)	
High SRT allowing slow-growing organisms to accumulate	
Combined COD, solids and nutrient removal in a single unit	
Rapid start up	
Sludge bulking not a problem	
Modular/Retrofit	

Laboratory experiments at the Dep. of Civil and Environmental Eng., Stanford University (USA) for examining the operation of an aerobic MBR.

Objectives:

- **determining the maximum membrane flux that can be sustained in long term**
- **tracking the variation of flux and transmembrane pressure during the operation**
- **examining the effects of different operational parameters (backwash, initial flux) and low pH (<6) on MBR performance (fouling, pollutant removal efficiency)**
- **experience for the start-up and operation of a MBR**

Experimental system



Ceramic Membrane Unit

Kubota ceramic membrane
0.1 μm pore size
0,06 m^2 total surface

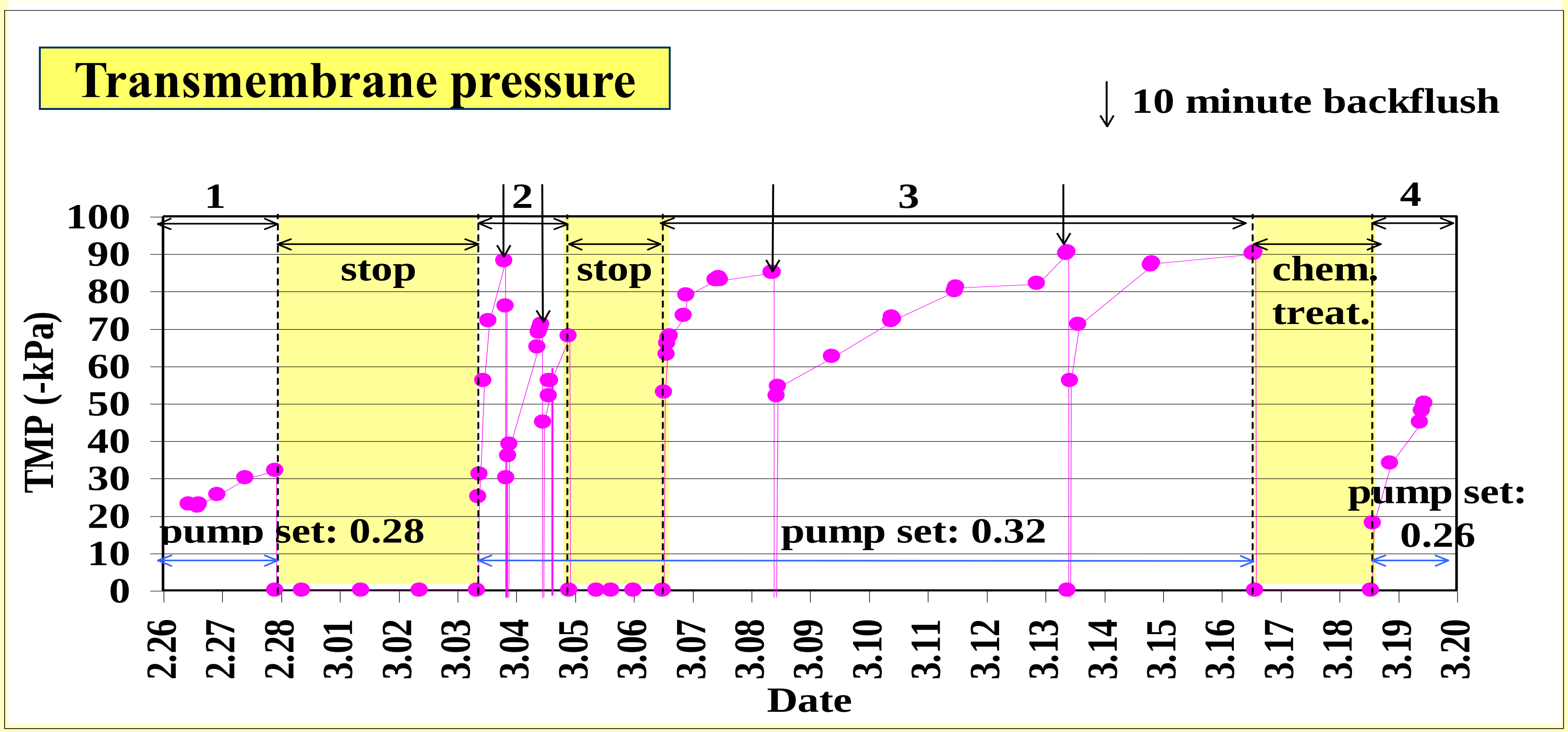
Composition of synthetic wastewater

Chemicals	Influent Concentration (mg/L)
COD (as CH_3COONa)	108 (76-145)
NH_4 – N (as NH_4Cl)	63 (59-72)
P (15% K_2HPO_4 & 85% KH_2PO_4)	11 (10.1-11.4)
Yeast extract	5 (based on calculation)

Measurements

- **Transmembrane pressure** **(negative pressure = suction applied to the membrane)**
- **Water flow**
- **Chemical parameters:**
  COD, NH_4-N, NO_3-N, PO_4-P in the
  - **influent**
  - **reactor**
  - **effluent**

Operation periods



Operation periods

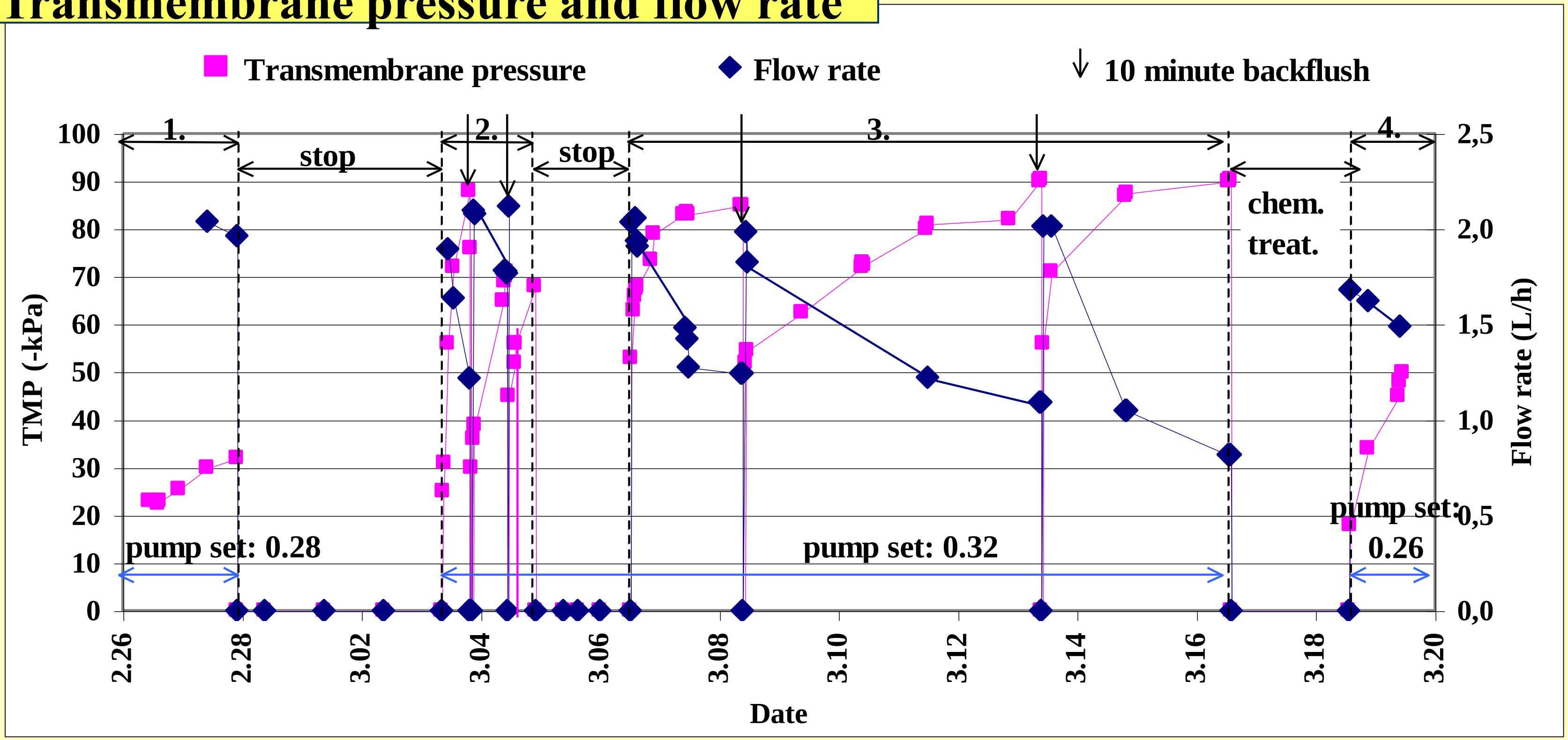
1. Unstable conditions
2. 10 minutes backwash periods
3. Equalization tank installed, inflow and outflow rates: 0.72 L/h
4. Lower pump speed, longer backflush periods

Stops

Only aeration
Only aeration
Chemical treatment

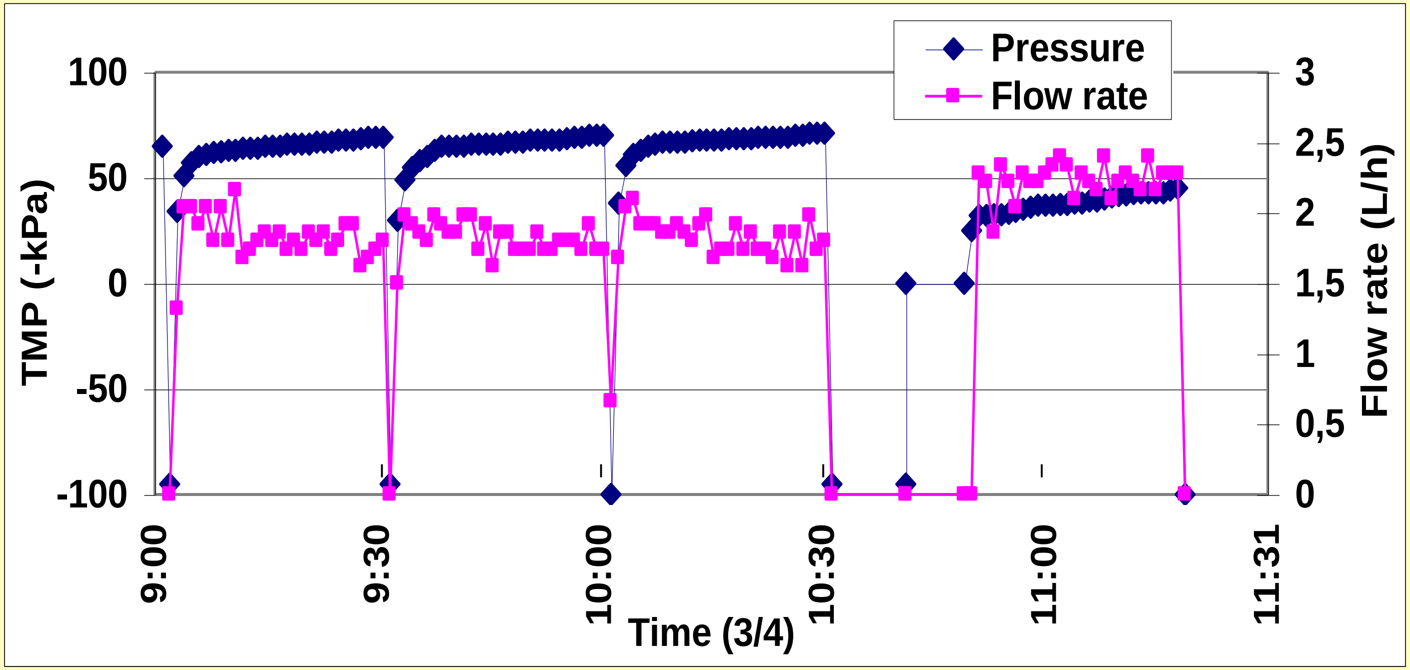
Results

Transmembrane pressure and flow rate



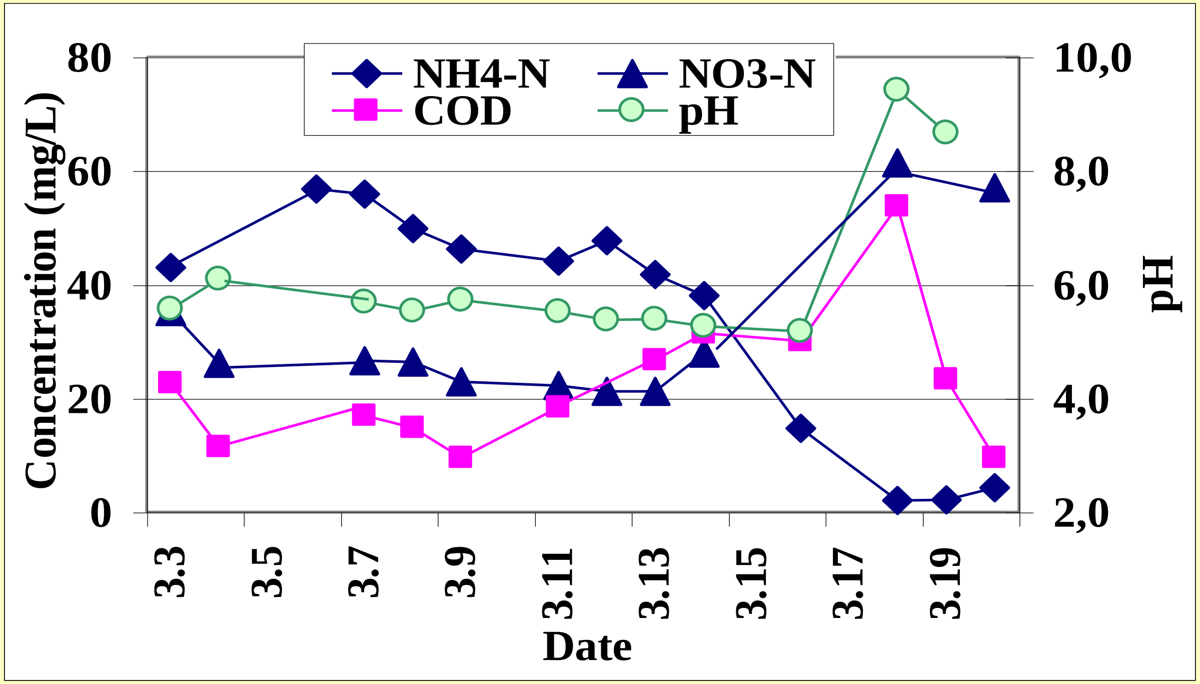
TMP	Flow rate
1. < 32 kPa	1. Initally 1.8-2.0 L/h (~720-780 L/m²/d) 1.9-2.05 L/h
2. Rapid increase to 88 kPa in one day, 10 min. backflush helps	2. Decreased to 1.2 L/h - restoration >1.75 L/h
3. 52 - 90.5 kPa – severe fouling	3. 0.8 L/h
4. <50 kPa for 3 days	4. 1.5-1.7 L/h (lower pump speed)

Effect of backwash and physical cleaning



- Regular backwash: 50 seconds in every half an hour
- Helps mitigating fouling
- Beginning of each period: lower TMP and higher flux
- 10 min backwash + physical cleaning recovered the permeability:
- TMP = 85 kPa
  - ⇒ 10 min backwash: 75 kPa
  - ⇒ 10 min backwash + phys cleaning: <40 kPa

Chemical parameters of the effluent

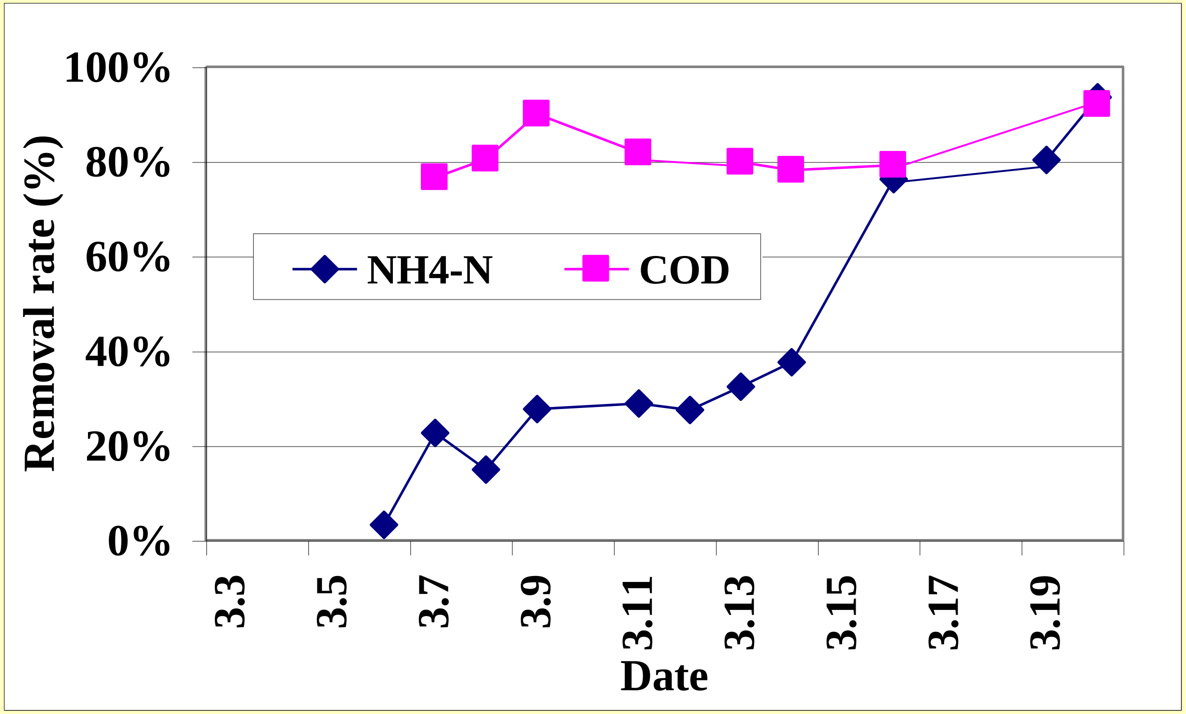


- No pH control until 3/13
- after that $NaHCO_3$ was added
- pH is low in the first periods

- **NH_4-N**
  - high for long time
  - by the end of Period 3. it reached 15 mg/L
  - at the very end: only 2-4 mg/L
- **NO_3-N**
  - stable until 3/13
  - by the end almost all NH_4 converted to oxidised forms

- **COD**
  - usually <30 mg/L
- **PO4-P**
  - Practically no removal

Pollutant removal rates



- NH_4-N
  - Below 40% when low pH
  - >90 % at th end
- COD
  - 75-90%
  - No significant change

Conclusions (1)

- very rapid fouling during the experiment
- actions like backwashing and physical or chemical cleaning restore the majority of membrane permeability
- more frequent short time backwashing, regular 10 min backwashing and physical/chemical cleaning is necessary
- backwash with air or with the combination of air and water should also be tested.
- higher aeration rate can be applied to increase shear in the vicinity of the membrane surface

Conclusions (2)

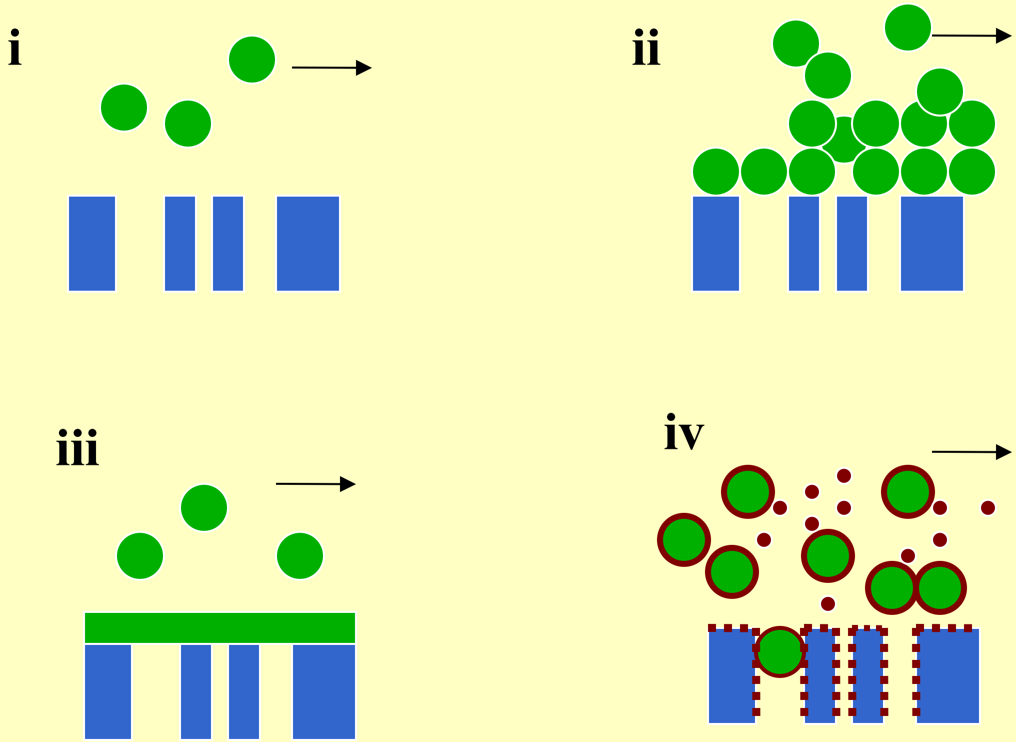
- **Automatic system control is needed in order to keep constant membrane flux and stable hydraulic conditions. Real time monitoring of flow rate and transmembrane pressure is necessary for control.**

- **No higher flow rate than 1.8 L/h (720 L/m^2/d) is recommended with this specific membrane module.**

- **Sodium hydro-carbonate should be added continuously to ensure the favourable pH range for nitrifiers (between 6.8 - 8). (online pH meter and buffer self-feeding)**

Thank you

Simplistic illustrations of particles' effect on surface and performance



(i) No effect; (ii) concentration polarization;

(iii) Gel polarization; (iv) adsorptive fouling

Hydraulic and sludge retention times

- **Independent HRT and SRT**
- **high biomass concentration = high sludge age**

	MBR typical	MBR extreme	AS
HRT (h)	2-24		
SRT (d)	>15 (30)	infinite	8-15
MLSS (mg/l)	15 000 - 35 000	80 000	3000 - 7000

Biomass concentration

- MLSS >35 000 mg/l – operational problems
  - Oxygen transfer
  - Viscosity (mixing)
  - Membrane flux

Flux

- 5-300 $l/m^2/h$
- Depends on:
  - Transmembrane pressure
  - Crossflow velocity
  - Pore size
  - Biomass characteristics

Energy consumption

- High oxygen consumption
  - High biomass concentration
  - High minimum maintenance energy

- 2-10 kWh/m^3 (50-150 $l/m^2/h$)
- 10 times lower if submerged

Treatment performance

	Removal	mg/l
TSS	up to 99.9%	5
COD	60-99%	40
BOD_5	60-99%	5-30
TN	85-99%	~10mg/L
TP	11-75% (97%)	~1mg/L