Membrane Bioreactors (MBR)

Membrane Classification

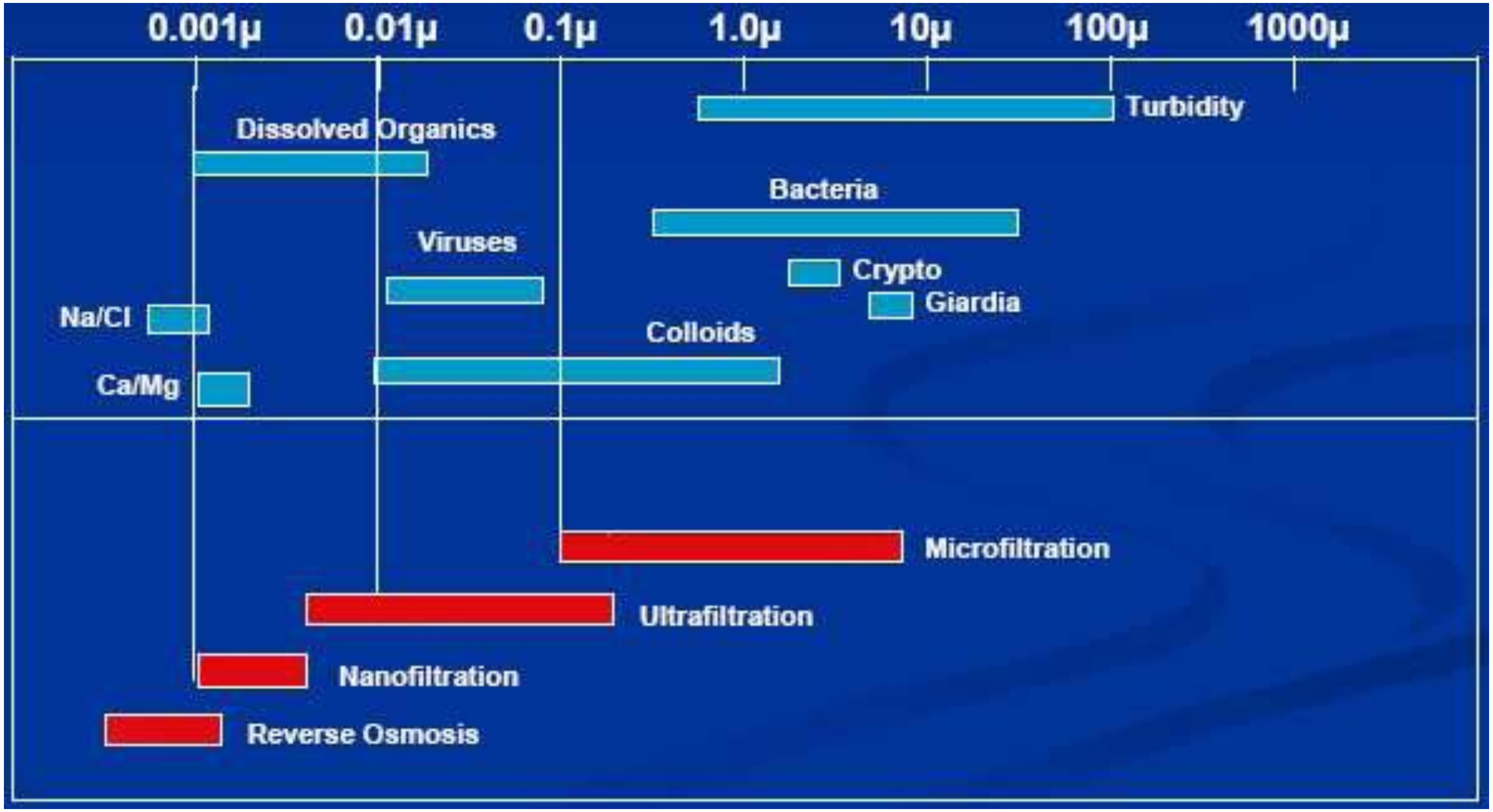
Microfiltration (MF)

Ultrafiltration (UF)

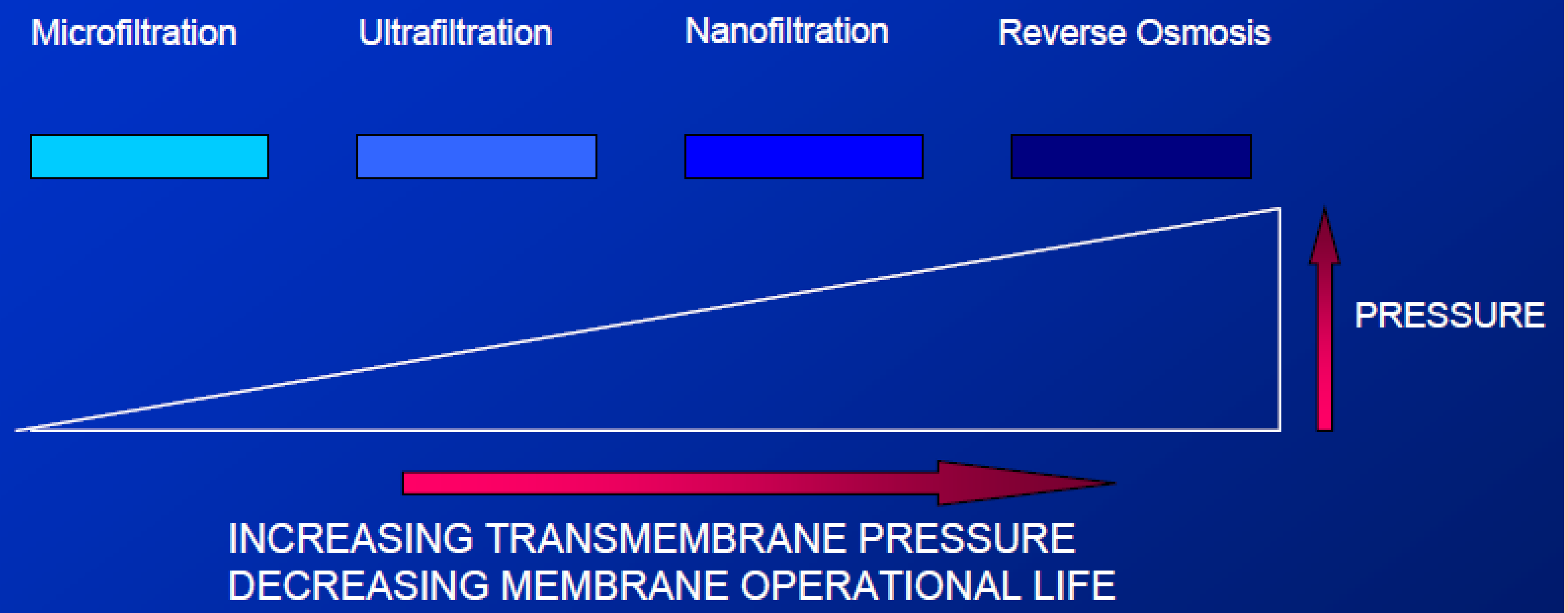
Nanofiltration (NF)

Reverse Osmosis (RO)

Comparison of Membrane Filtration Processes Contaminants Rejected



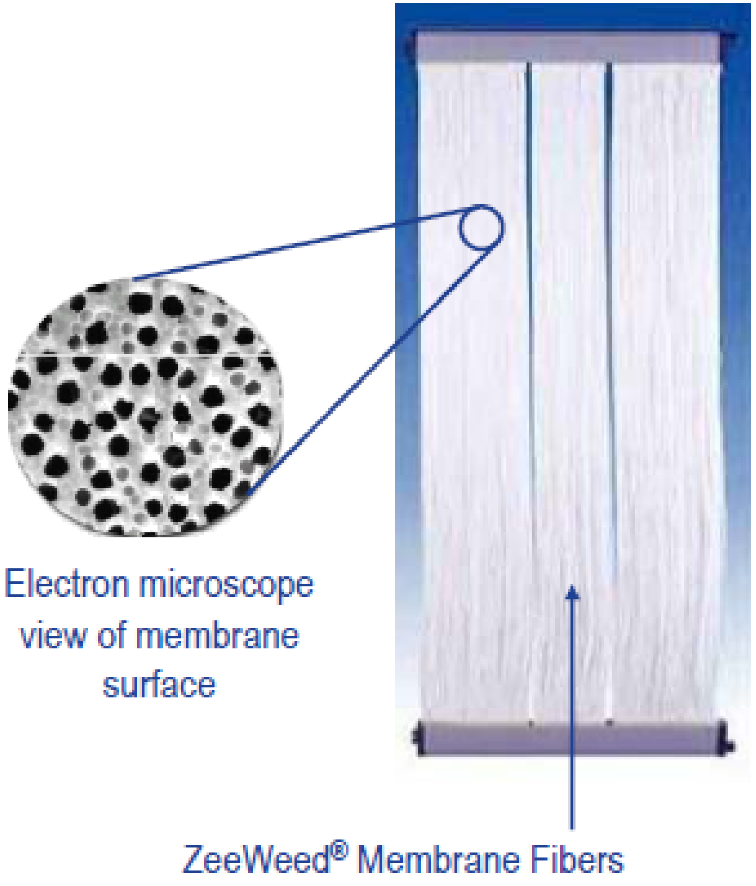
Membrane Spectrum



Filtration in the 0.1 micron range is the most widely used membrane type in wastewater treatment applications.

How Membranes Work

- Membrane fibers have billions of microscopic pores on the surface
- The pores form a barrier to impurities, while allowing pure water molecules to pass
- Water is drawn through the pores using a gentle suction

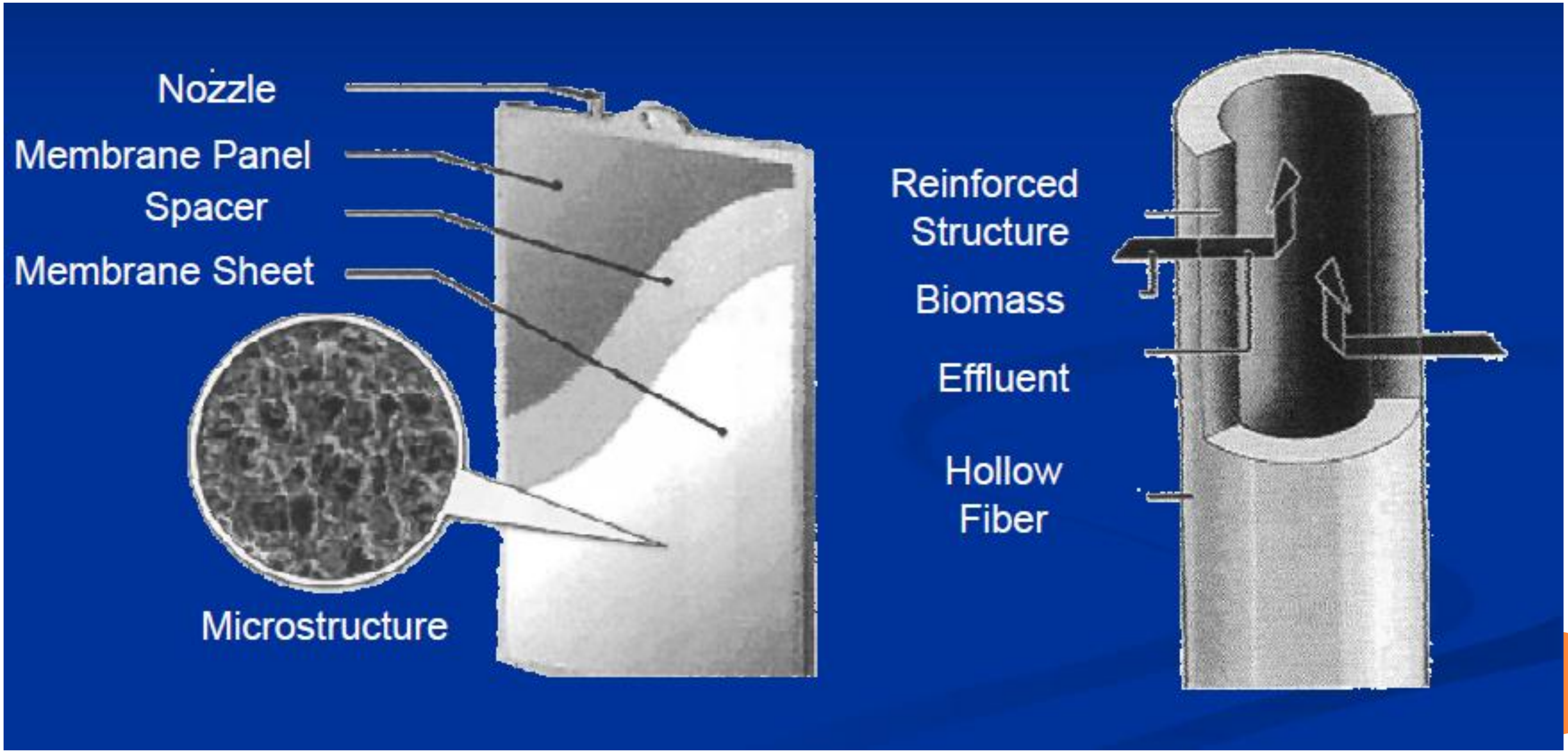


General Process Characteristics

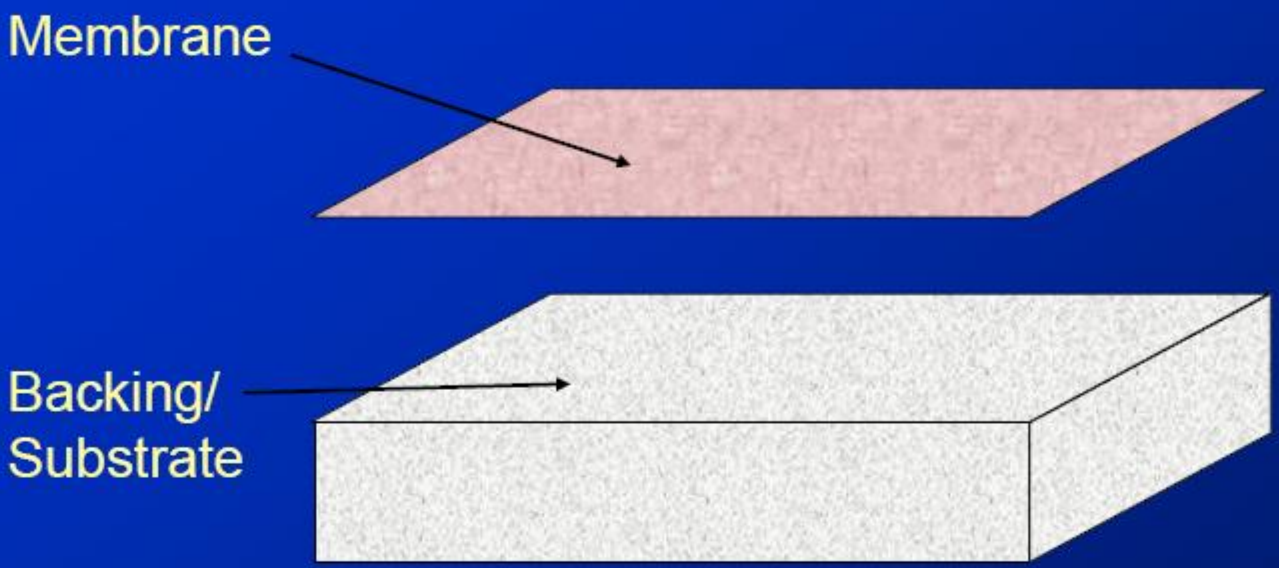
- MF and UF
  - Low Pressure
  - Size Exclusion
  - Pathogenic bacteria and some viruses
  - MBR Systems, polishing and post treatment
- NF and RO
  - Higher Pressure
  - Size Exclusion plus diffusion charge
  - Pathogenic bacteria, viruses, dissolved solids and ions
  - Secondary polishing and post treatment

TYPICAL TYPES OF MEMBRANES

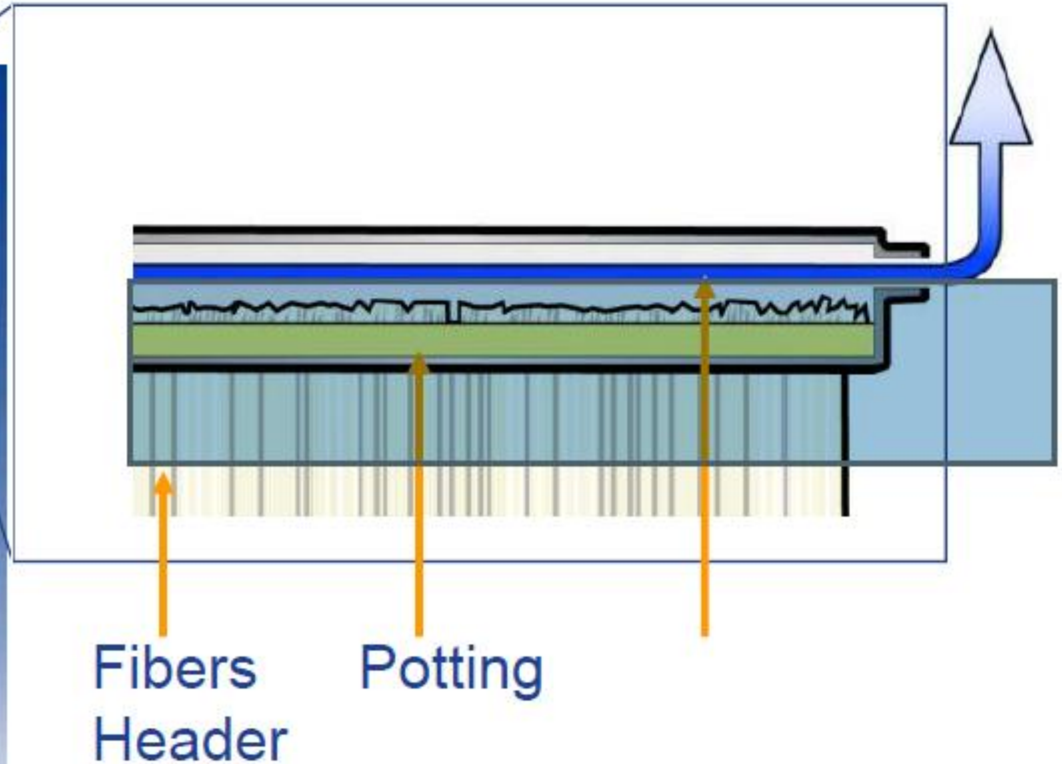
FLAT PLATE HOLLOW FIBRE



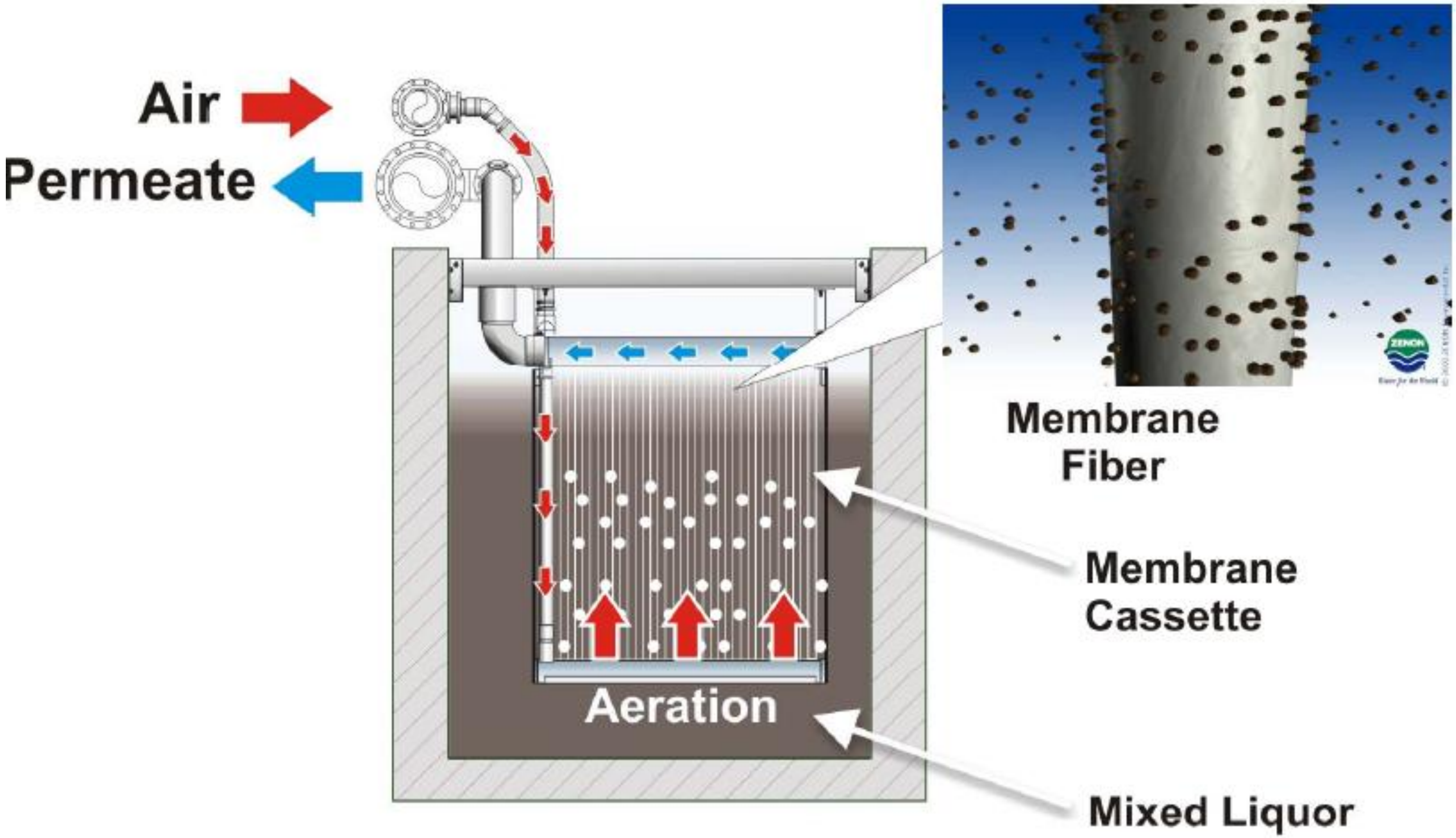
Laminated Membrane



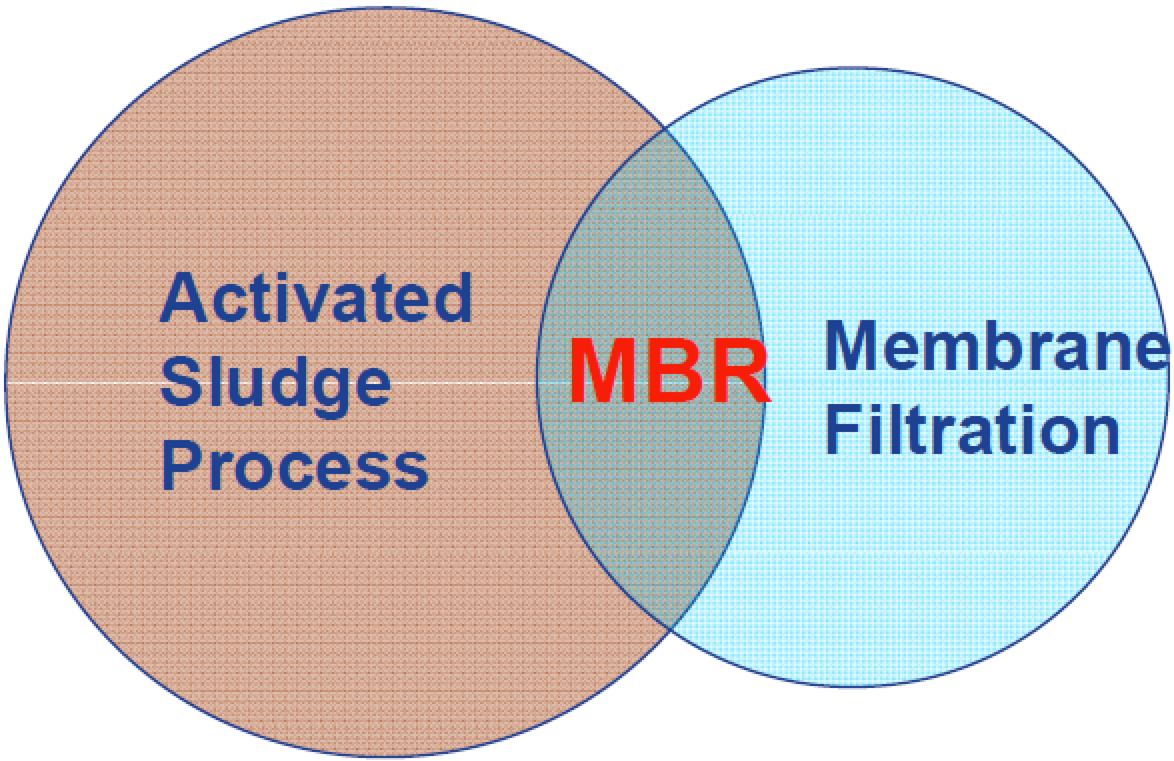
- Membrane is applied to a substrate or backing for support
- Mechanical bond is critical



Modules are composed of thousands of membrane fibers


Air
Permeate
Membrane
Fiber
Membrane
Cassette
Aeration
Mixed Liquor

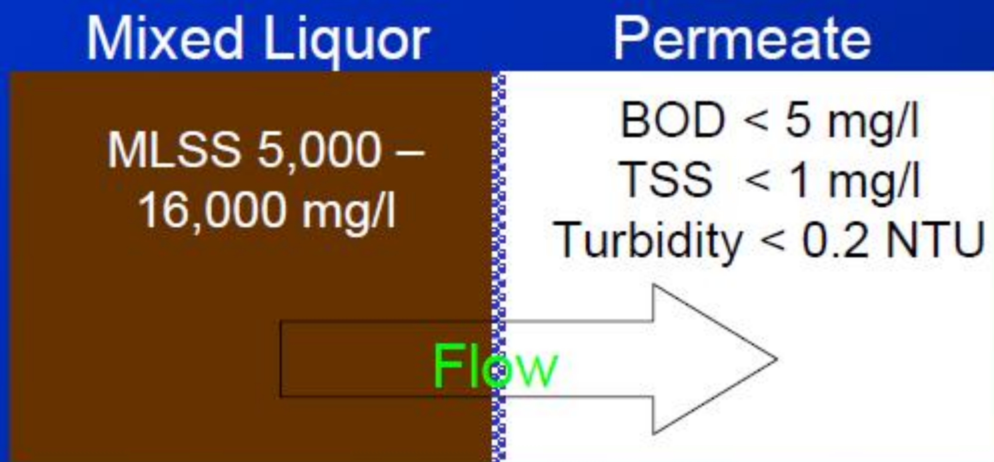
Membrane bioreactor



Stable Biological Treatment Process

Absolute Solids Separation

Low-Pressure Polymeric Membrane

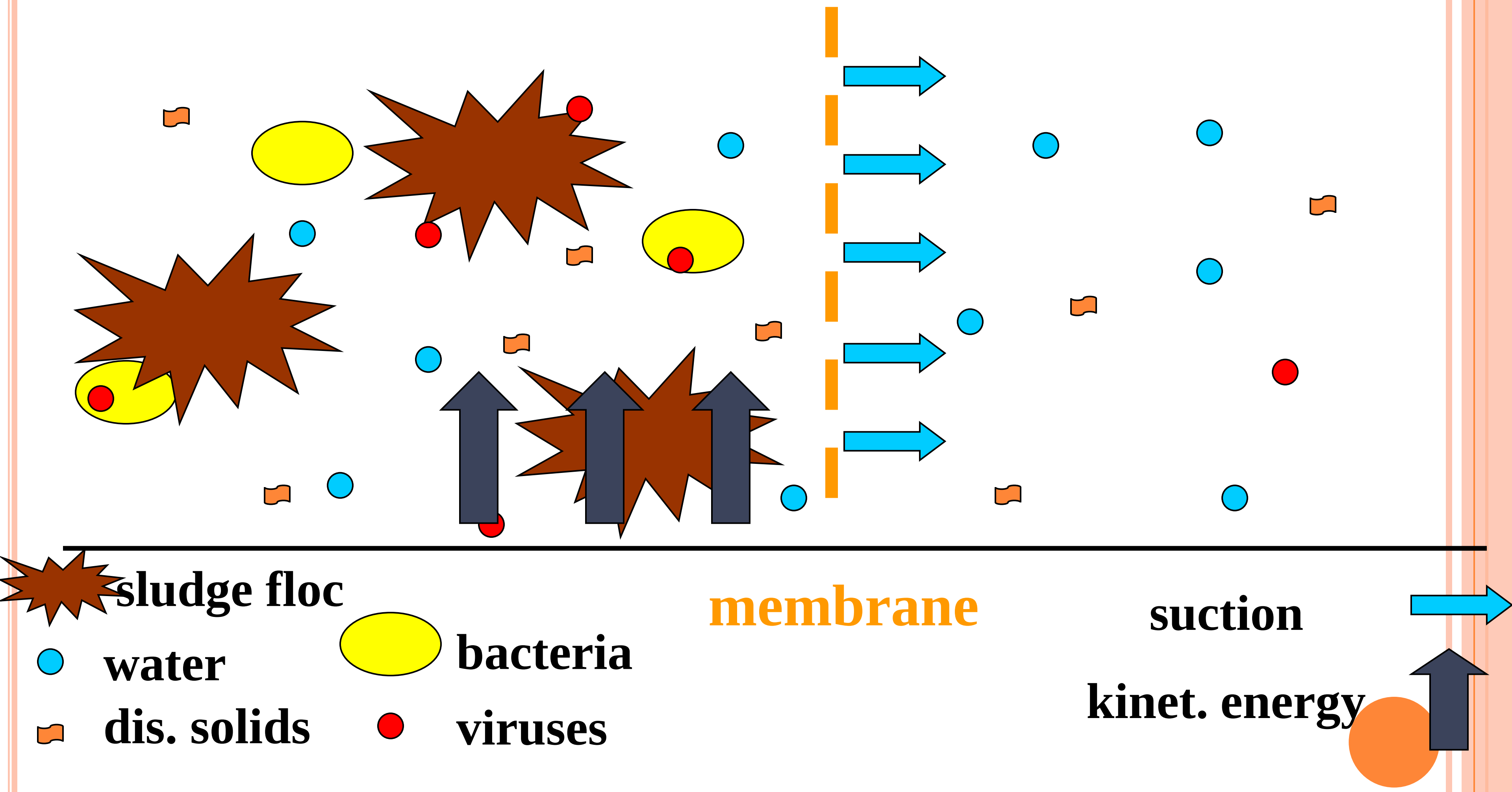


Effluent Water Quality

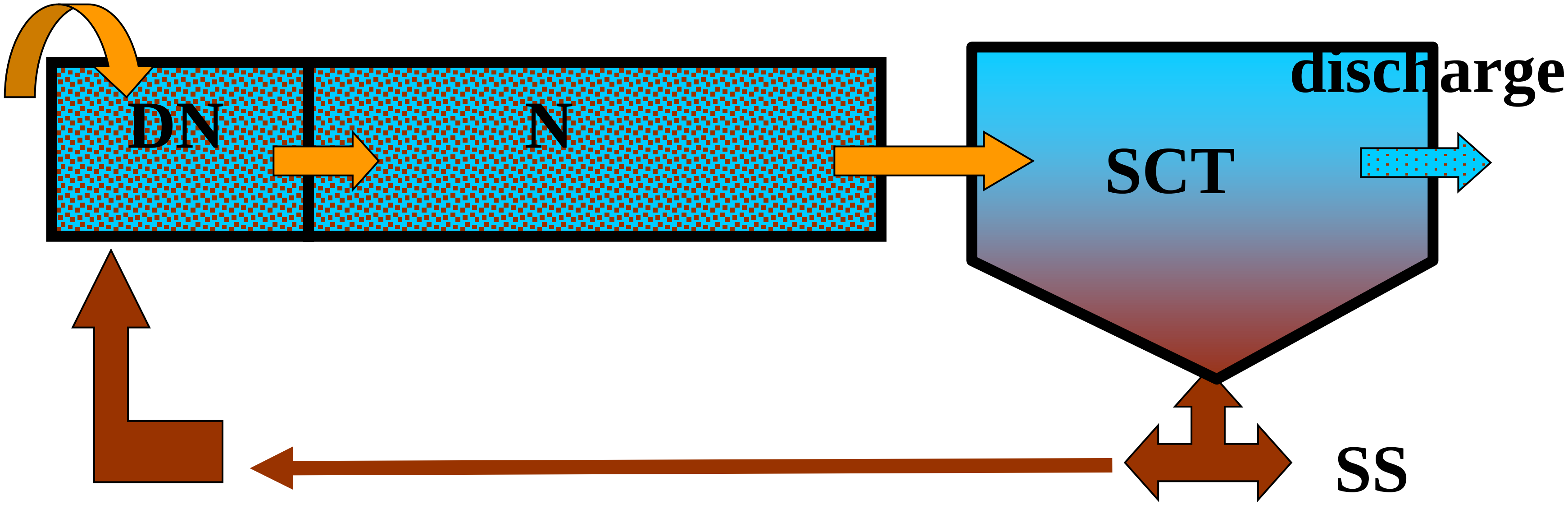
Membrane provides an absolute barrier and effluent quality is no longer a concern.

	ASP Effluent	MBR Effluent
TSS, mg/L	<30	ND (<2)
Turbidity, NTU	2 to >10	<0.2
Total Coliform, #/100 mL	10,000 to 100,000	ND to 100
BOD_5, mg/L	<2 to 30	ND (<2)

PROCESS BASICS

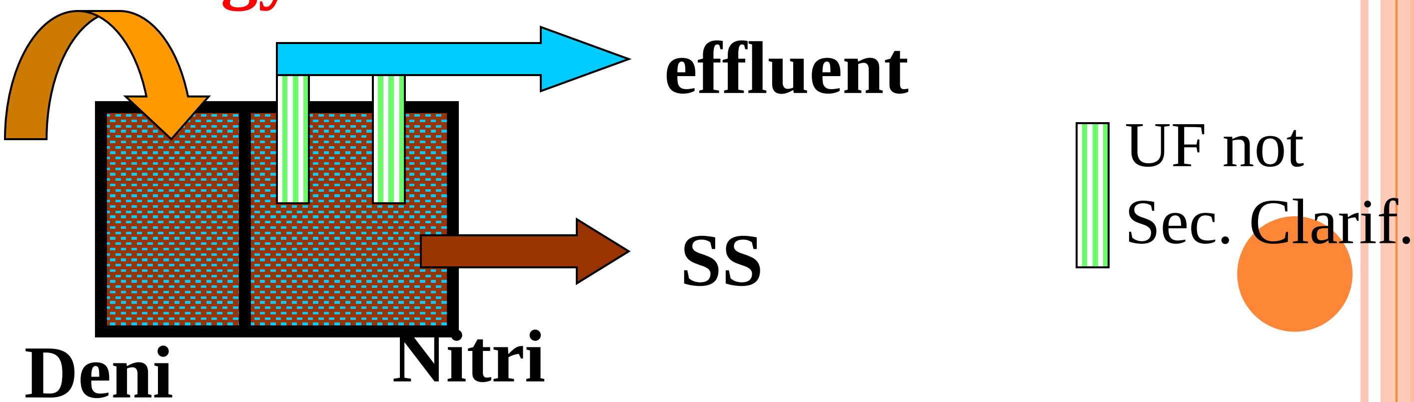


PROCESS BASICS



conventional technology

membrane technology

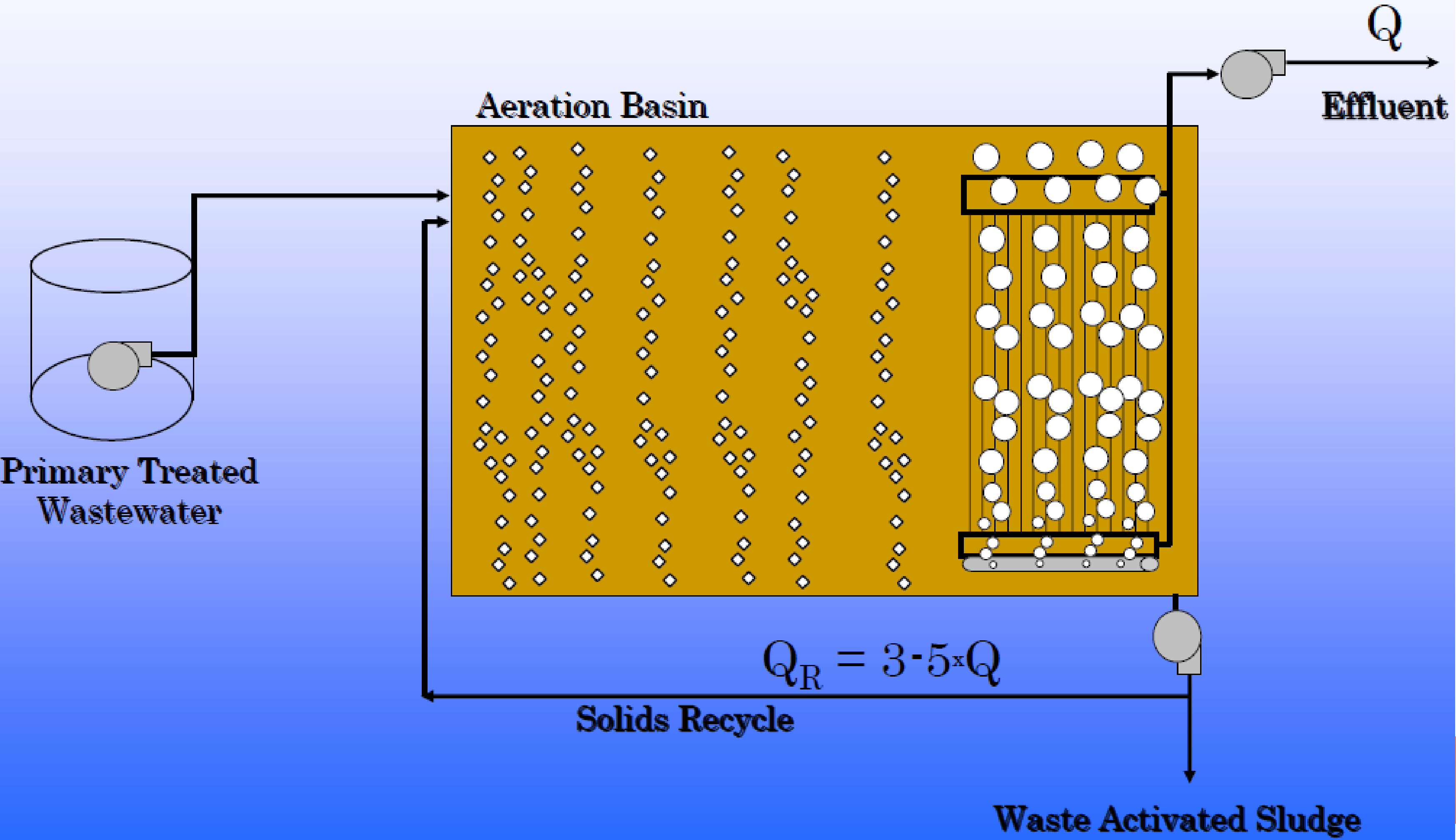


Two configurations:

- External
- Submerged

- Pressure driven→commonly in tubular form and external
- Vacuum driven

Submerged MBR (SMBR)



External MBR (EMBR)

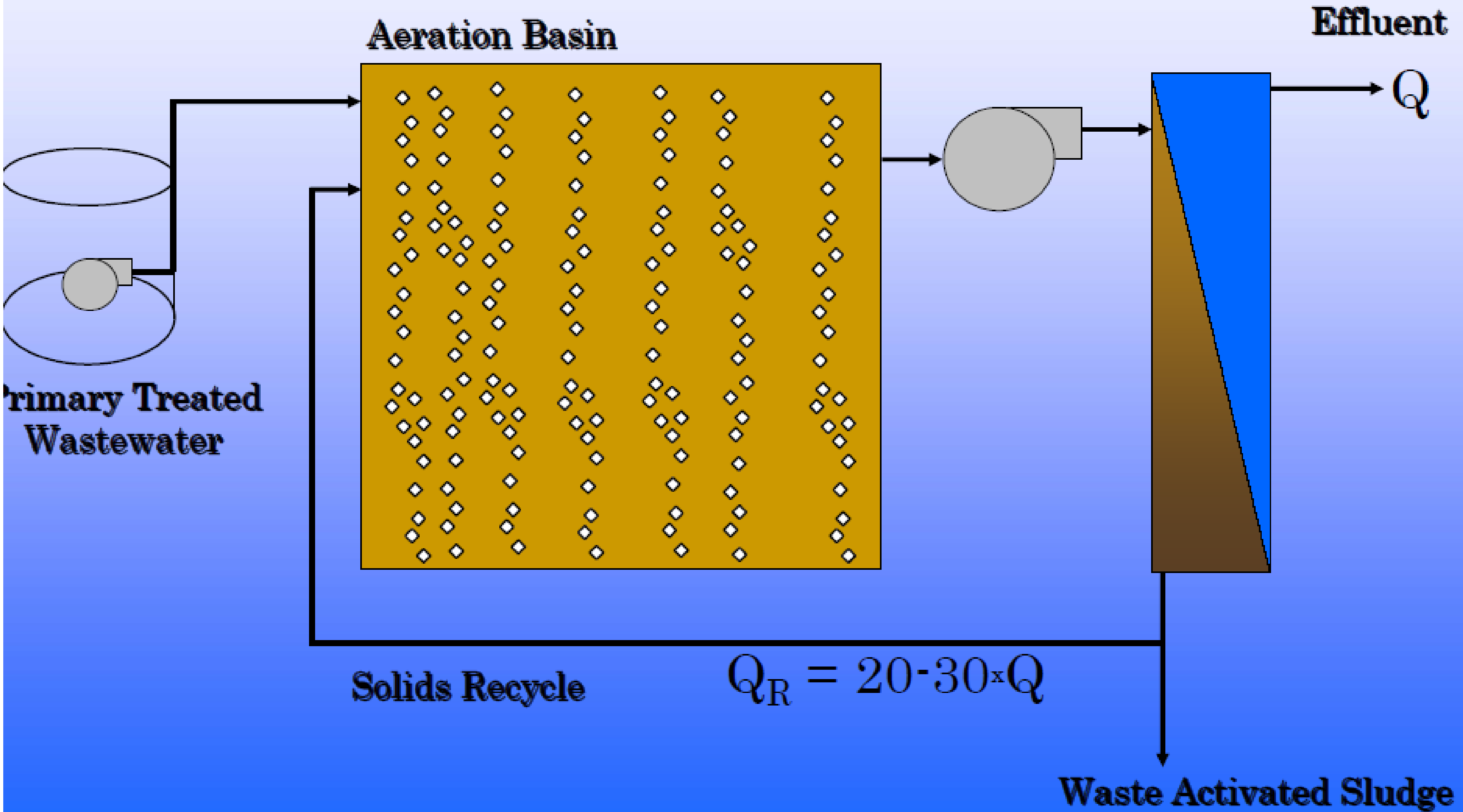
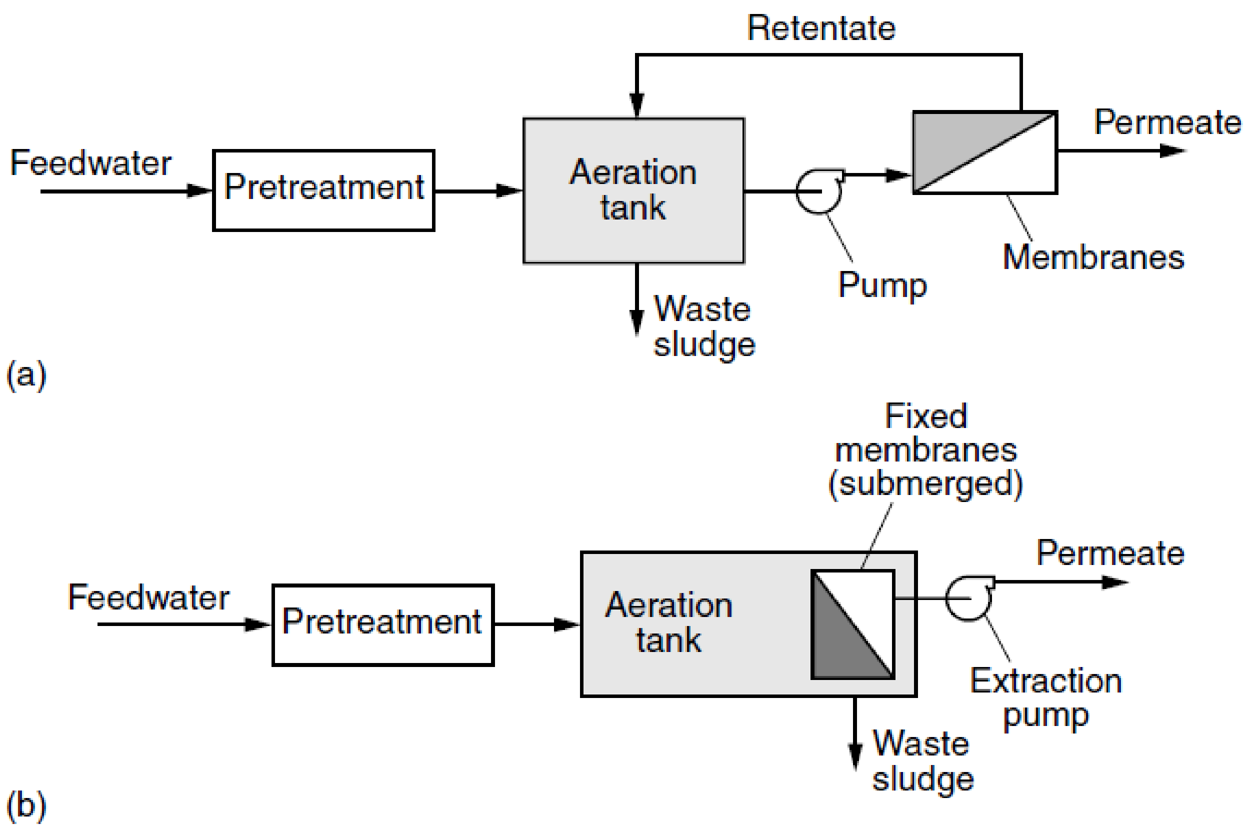
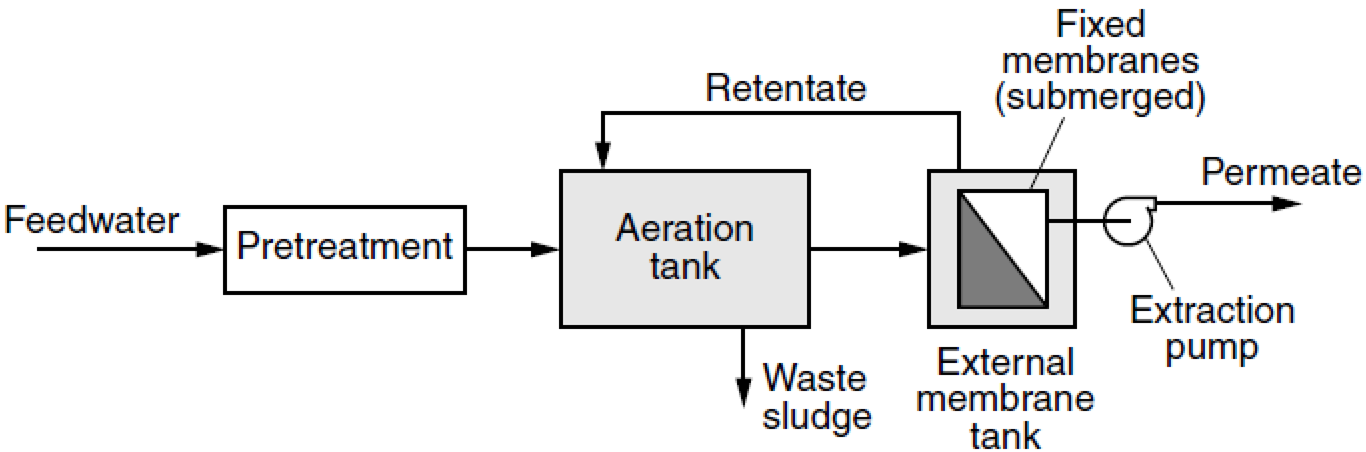


Figure 7-12

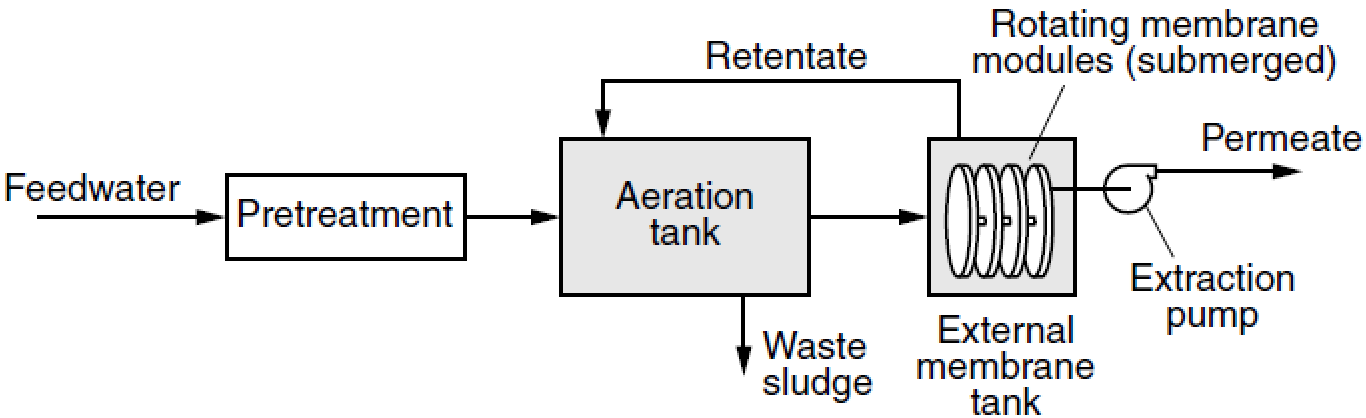
General types of membrane bioreactors: (a) with external pressure-driven membrane, (b) integrated submerged, (c) with external submerged, and (d) with external submerged rotating membrane.





Retentate
Fixed membranes (submerged)
Permeate
Feedwater
Pretreatment
Aeration tank
Extraction pump
Waste sludge
External membrane tank

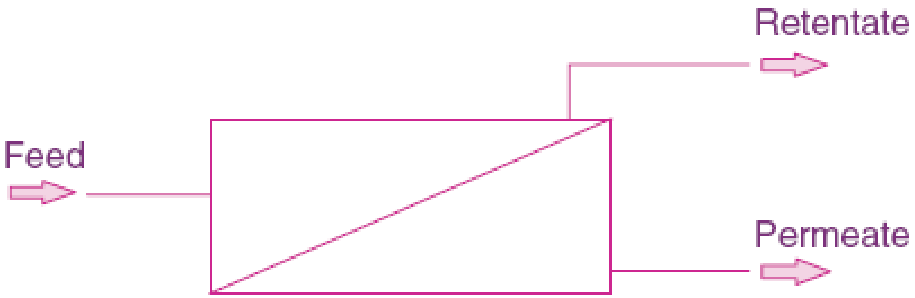
(c)



Retentate
Rotating membrane modules (submerged)
Permeate
Feedwater
Pretreatment
Aeration tank
Extraction pump
Waste sludge
External membrane tank

(d)

Common terms and definitions



Common terms and definitions (Contd)

- Gross Flux
  - The volume of water that passes through a membrane per unit time and per unit surface area of the membrane. Flux is often normalized based on temperature.
  - Gross Flux=Instantaneous Permeate Flow /Surface Area

Common terms and definitions (Contd)

- Net Flux
  - The total Permeated Flow over 24 hours divided by the total surface area expressed in gallons per minute per square foot.
  - Net Flux=Total Permeate Flow/ Surface Area
- Total Surface Area
  - The total surface area represents the total membrane surface area available for treatment in a membrane system..

Common terms and definitions (Contd)

- Transmembrane Pressure
  - The difference between average/concentrate pressure and the permeate pressure is the driving force.
  - The TMP is a means to assess fouling
  - TMP = feed pressure – permeate pressure
- Fouling
  - The build up of impurities on the membranes such as colloidal materials. Fouling reduces flux through the membrane and increase the TMP.
  - Micro fouling is the build up of impurities in the membrane pores.

Common terms and definitions (Contd)

- Permeability
  - The permeability of a membrane is the flux rate divided by the transmembrane pressure..
  - P = Flux / TMP
- Recovery
  - Recovery is the concept of restoring the hydraulic characteristics of the membrane.
  - Recovery is achieved by membrane cleaning.

Process variables

- Temperature
  - Viscosity of water increases, as water temperature decreases. →Permeability and flux rate decreases
- Pore size
- Membrane flux rate (L/m2.hr)
  - MLSS increases→flux rate decreases
  - Qpeak→design flux rate
- Membrane life

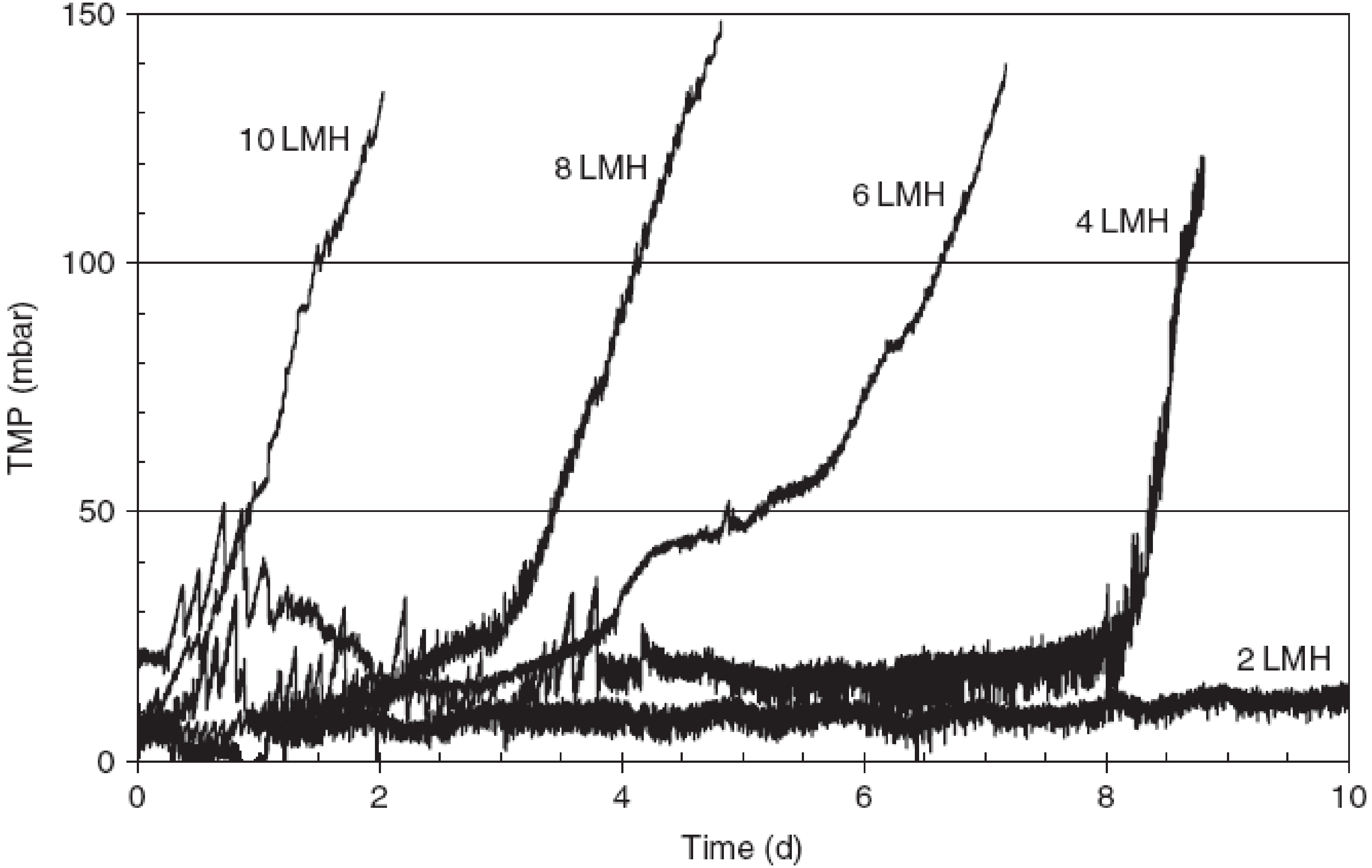
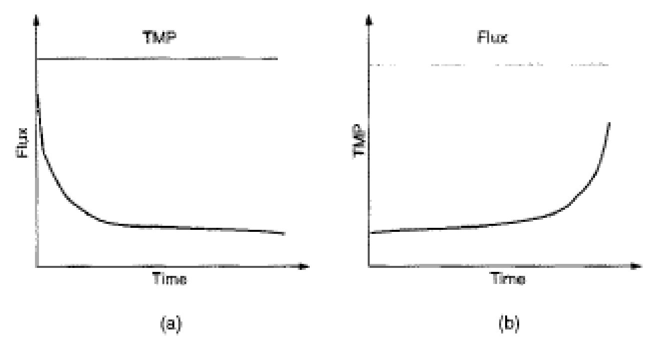


Figure 2.14 *TMP transients for sub-critical flux operation (Brookes* et al.*, 2004)*

- Constant TMP operation
- Constant flux operation→preferred mode, because it ensures a steady throughput.

Figure 2: Constant TMP operation and constant flux operation (a & b, respectively).



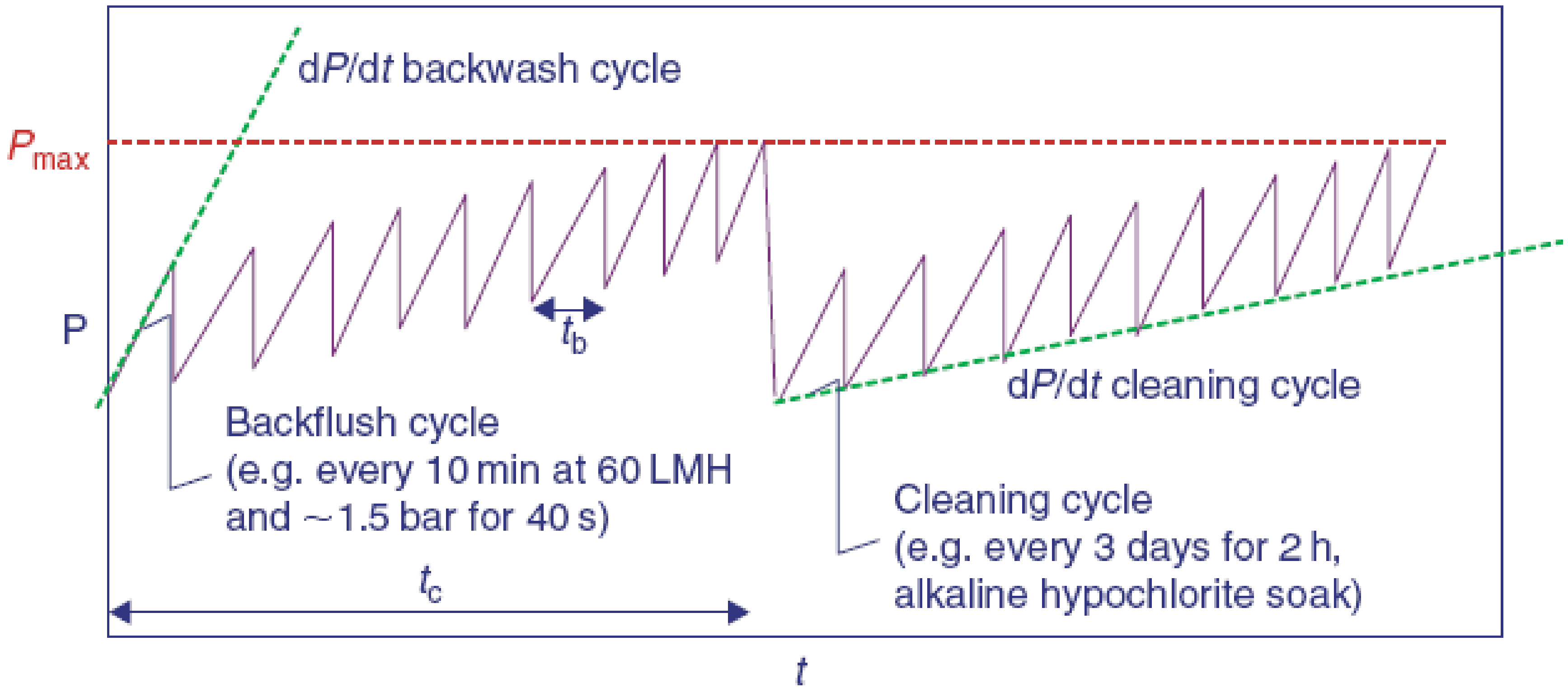


Figure 2.11 Pressure transient for constant flux operation of a dead-end filter

System Advantages

- Small footprint
- Complete retention of suspended solids and most soluble compounds
- Independant control of hydraulic and solid retention times
- Ability for slow-growing species to flourish (nitrifying bacteria, etc.)
- High loading rate capability
- Combined COD, solids and nutrients removal
- Low/zero sludge production→high SRT
- Rapid start-up
- Eliminates problems due to settling
  - High biomass concentrations
  - Bulking or rising sludge not problem
- Effluent disinfection

System disadvantages

- Membrane costs
- High capital costs
- Membrane complexity
- Membrane fouling
  - Pretreatment of feed or bach flushing with water/air or chemical cleaning is used.
- Operation and maintenance
- Energy costs
- Aeration limitations

Leading Manufacturers

- Zenon Environmental Inc. (CANADA)
- General Electric

} Hollow Fiber

- Mitsubishi Rayon Cooperation (JAPAN)
- Kubota Cooperation (JAPAN)→Flat Plate
- US Filter (USA)

	Zenon	Kubota	Mitsubishi	US Filter
Membrane				
Type	Hollow fiber	Plate	Hollow fiber	Hollow fiber
Configuration	Vertical	Vertical	Horizontal	Vertical
Pore size	0.04 µm	0.4 µm	0.04 µm	0.04 µm
Module size	31.6 m^2	0.8 m^2	105 m^2	9.3 m^2
Location	Cell compartment	Throughout basin	Throughout basin	Cell compartment
Screening size	≤ 2 mm	≤ 3 mm	≤ 2 mm	≤ 2 mm
Flux management				
m^2/m^3h	0.37	0.53	0.73	0.18
Aeration cycle	10 sec on 10 sec off	Constant	Constant	Constant
Flux rate				
Average, l/m^2, h	17-25	17-25	8.5-12	17-25
Peak hour (≤ 6 hrs) l/m^2h	<42	<59	equalize	<51
Maintenance				
Clean				
Type	Backpulse and relax	Backpulse	Relax	Backpulse or relax
Frequency	hourly	1 min/15min	2 min/12 min	1 min/15min
Recovery clean				
Type	Chem. Soak	Chlorine Backwash	Chlorine Backwash	Chem. Soak
Location	Drained cell	In situ	In situ	Drained cell
Frequency	≥ 3 months	≥ 6 months	≥ 3 months	≥ 3 months
Biological Parameters				
SRT, days	10-15	15	20	10-15
MLSS, mg/l	≤ 10 000	≤ 10 000	≤ 10 000	≤ 10 000

Operating Conditions (Integrated System)

Table 1
Operating conditions for submerged MBR [2–6]

Parameter	Value
Flux	
instantaneous, L/(m^2 h)	25–35
sustainable in long term operation, L/(m^2 h)	15–30
Transmembrane pressure, kPa	20
Biomass concentration, gMLSS/L	5–25*
Solids retention time (SRT), d	>20
Sludge production, kgSS/(kgCOD d)	<0.25
Hydraulic retention time (HRT), h	1–9
Food/micro organisms ratio (F/M), kgCOD/(kgMLSS d)	<0.2
Volumetric load, kgCOD/(m^3 d)	up to 20
Air flow rate, Nm^3/h per module	8–12
Operational temperature, °C	10–35
Operating pH	~7–7.5
Backwash frequency, min	5–16
Backwash duration, s	15–30
Energy consumption for filtration, kWh/m^3	0.20–0.40
for membrane aeration, %	80–90
pumping for permeate extraction, %	10–20

*12–15 g/L is advised, higher concentrations can cause operational problems like clogging of the membrane and decreased oxygen transfer efficiency

Important points

- Pretreatment as screening and grit removal is important
  - 3mm screening→hair and fiber can pass, wrap around the membrane
  - Many manufacturers now use 2mm screen
  - Best is to use 2mm, then 1mm screen
- Recommended MLSS: 8000-12000 mg/L to optimize aeration, flux and cleaning frequency
- R=4, to prevent solids buildup in the membrane area
- High peaking factors→ equalization req’d

Air supply

- Air suply:
  - For biological process
  - For cleaning the membrane to prevent fouling
- Air for cleaning can exceed the air requirement for biological processes
- High MLSS concentration reduces aeration efficiency→higher energy input requried

Figure 7-20

Effect of MLSS on alpha values for fine pore aeration in MBRs. [Sources: α1—Bratby et al. (2002) for coarse bubble aeration, α2—ibid. for fine bubble aeration, α3—Wagner et al. (2002), and α4—Thompson (2004).]

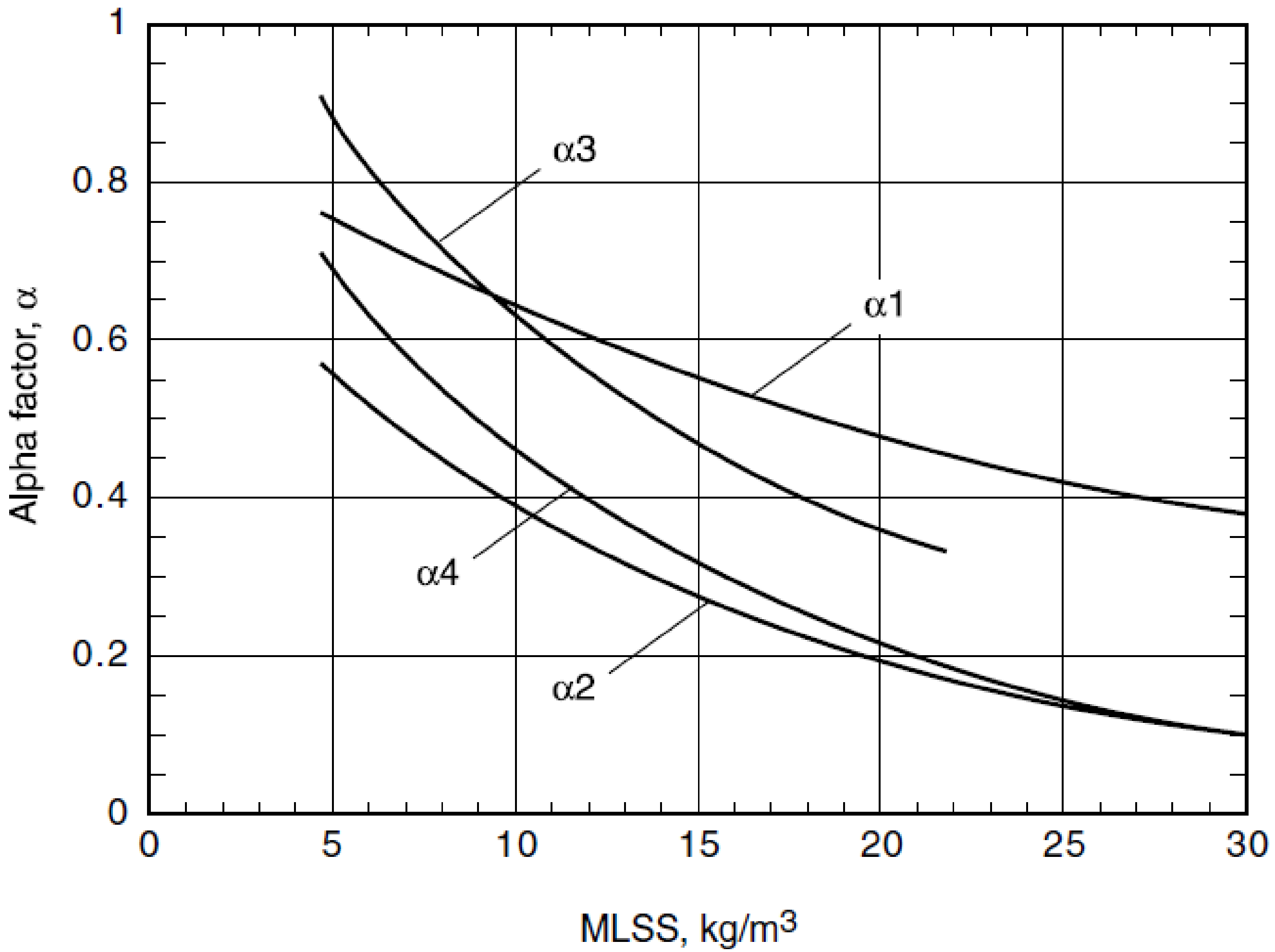
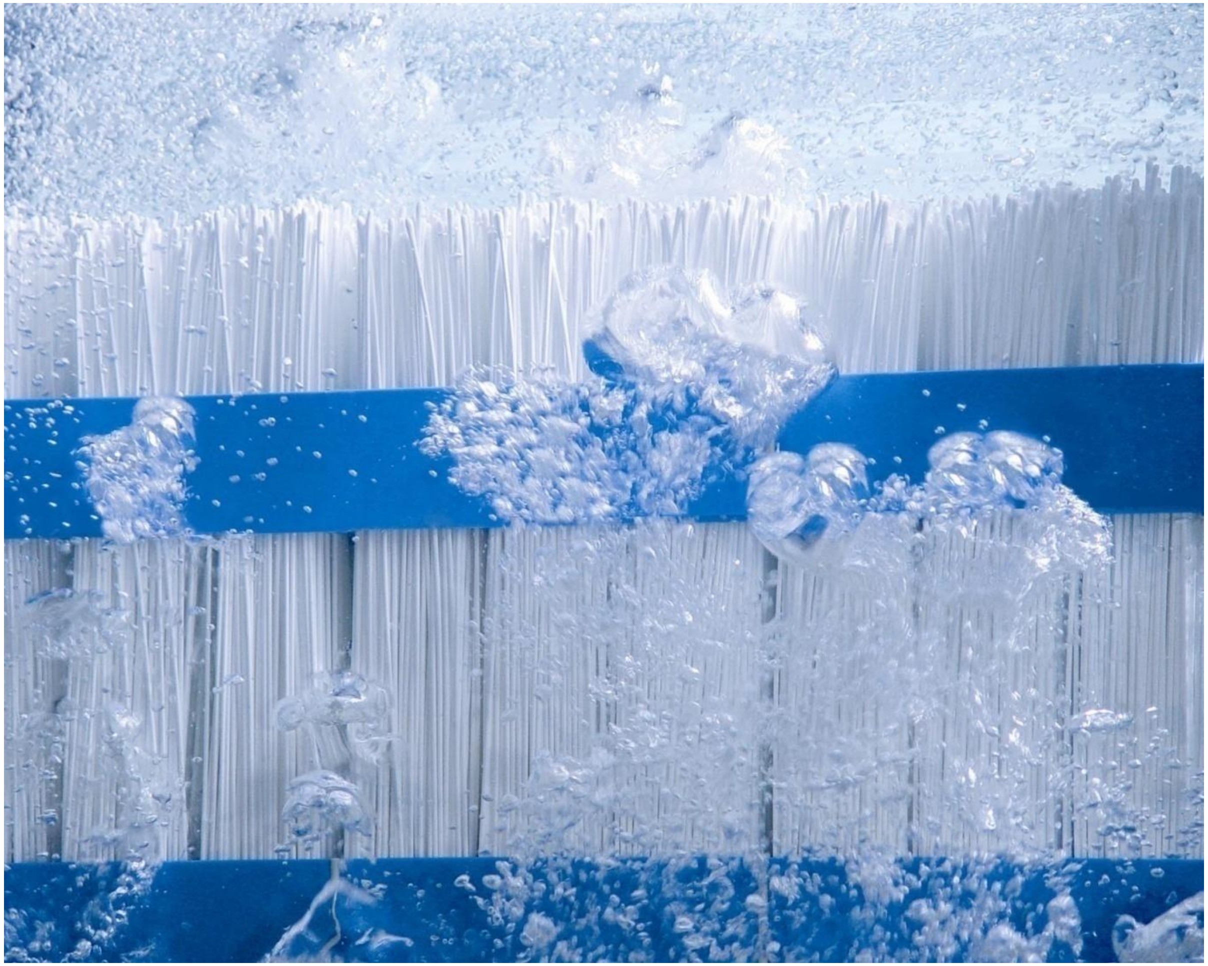


Table 3.1 Main features of aeration systems (Judd, 2006)

	Fine bubble	Coarse bubble
Bubble size	2–5 mm[a]	6–10 m[a]
OTE (percentage of O_2 transfer per m depth)	3–10%[b]	1–3%[b]
Mechanical component	Air blower	Air blower
Diffuser type	Ceramic or membrane diffuser disk, dome or tube	Steel or plastic disk or tube
Shear rate[c]	Bubble velocity $\propto d^2$ (from Stokes Law). The small bubble sizes provide lower velocity and hence smaller shear forces.	Bubble velocity, and so shear, is higher than fine bubble aeration since the larger bubbles rise faster than small bubbles.
Diffuser cost[d]	Approximately £40 per diffuser	Approximately £15 per diffuser

[a]EPA, 1989.
[b]Data from survey of manufacturers and from literature study. The large variation in the efficiency data for fine bubble aeration is attributed to changes in the distribution of the diffuser nozzles over the tank floor and diffuser age. Fine bubble diffusers are susceptible to fouling and oxygen transfer efficiency can decrease up to 19% over 2 years of operation.
[c]Shear rate is a measure of propensity to ameliorate membrane fouling (Section 2.3.7.1).
[d]Data obtained from manufacturer quotes for use as a guideline only.



Chemical cleaning of membrane

	Type	Chemical	Conc. (%)	Protocols
Mitsubishi	CIL	NaOCl	0.3	Backflow through membrane (2 hr) + soaking (2 hr)
		Citric acid	0.2	
Zenon	CIP	NaOCl	0.2	Backpulse and recirculate
		Citric acid	0.2-0.3	
Memcor	CIP	NaOCl	0.01	Recirculate through lumens, mixed liquors and in-tank air manifolds
		Citric acid	0.2	
Kubota	CIL	NaOCl	0.5	Backflow and soaking (2 hr)
CIL: Cleaning in line where chemical solutions are generally backflow (under gravity) inside the membrane.				
CIP: Cleaning in place where membrane tank is isolated and drained; the module is rinsed before being soaked in the cleaning solution and rinsed to remove excess of chlorine.				

Table 3.21 Summary of full-scale plant specific aeration demand data

Technology	Capacity MLD	Flux LMH	K LMH/bar	$SAD_m{}^2$, Nm/h	$SAD_p{}^2$ –	MLSS g/L
FS						
Kubota	1.9	20	350	0.75	32	12–18
	13	33	330	1.06	32	8–12
	4.3	25	680	0.56	23	na
Brightwater	1.2	27	150	1.28	47	12–15
Toray	0.53	25	208	0.54	22	6–18
	1.1,i	21.6	1500	0.4	19	22
Huber	0.11	24	250	0.35	22	ns
Colloide	0.29	25	62.5	0.5	20	ns
HF						
Zenon	2	18	95	1	56	15
	48*	18	144	0.29	16	8–10
	0.15*,i	12	71	0.65	54	10–15
	50*	25	175	0.4	17	12
Mitsubishi Rayon	0.38	10	30	0.65	65	12
Memcor	0.61	16	150	0.18	11	12
Asahi-kasei	0.9, i	16	80	0.24	15	8
KMS Puron	0.63	25	160	0.25	10	ns

*Intermittent aeration.
i – Industrial effluent feedwater.
na – Not applicable.
ns – Not specified.