Lecture 6

Membrane Applications for Drinking Water Production

Prof. Ir. Dr. ZAINI UJANG

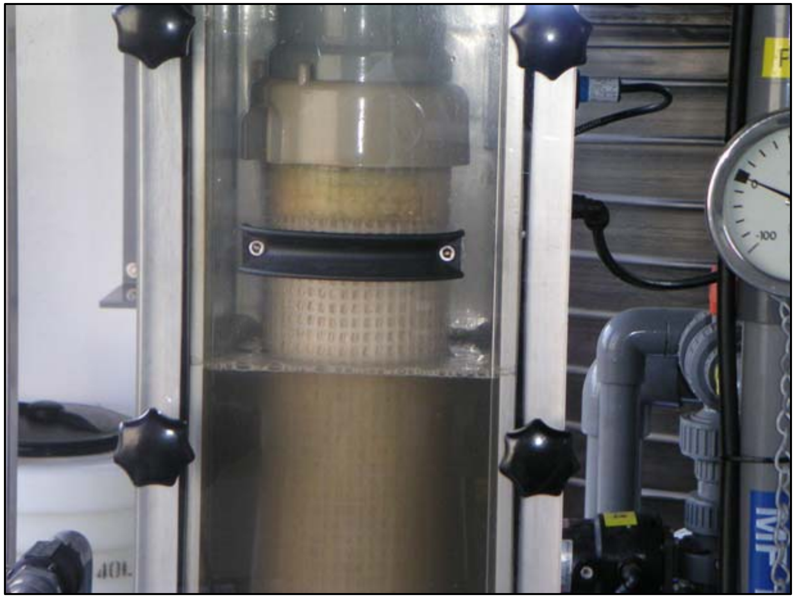
Ph.D., P.Eng. (M), C.Eng.(UK), C.Sci. (UK), C.W.E.M. (UK), MIEM, MIWA, DNS, PPT

Institute of Environmental & Water Resource Management (IPASA)
UNIVERSITI TEKNOLOGI MALAYSIA

Email: zaini@utm.my Homepage: http://web.utm.my/ipasa

Presentation Menu

Part 1: Introduction



Drinking water production

Sources of Water

- Seawater & brackish water
- Ground water
- Surface water
  - *Rivers*
  - *Lakes*
- Rainwater
- Treated used water

Drinking water production

Design Considerations

- Depends on raw water quality
- Design objectives set by health authority
- Quality → public health:
  - Chemical aspects
  - Microbiological aspects
  - Physical aspects

Drinking water production

WHO Guidelines, Food Act

Quality → public health:

- Chemical aspects
- Microbiological aspects
- Physical aspects

Ecotoxicology studies

↓

Quality guidelines

Drinking water production

WHO Guidelines (1984)

- Microbiological aspects
- Biological aspects
- Chemical and physical aspects
- Radioactive materials

Drinking water production

WHO Guidelines – Microbiological aspects (1984)

Treated Water Entering the Distribution System

Feacal coliforms	0/100 ml
Coliform microorganisms	0/100 ml

Water in Distribution System

Feacal coliforms	0/100 ml
Coliform microorganisms	0/100 ml
Coliform microorganisms	3/100 ml (Occasional)

Bottled Drinking Water

Feacal coliforms	0/100 ml
Coliform microorganisms	0/100 ml

Drinking water production

WHO Guidelines – Chemical aspects (1984)

Compounds	Guidelines values (µg/L)	ADI (mg/kg body weight)
DDT (total isomers)	1	0.005
Aldrin & dieldrin	0.03	0.0001
Chlordane (total isomers)	0.3	0.001
Hexachlorobenzene	0.01	-
Heptachlor and heptachlor epoxide	0.1	0.0005
Gamma-HCH (lindane)	3	0.01
Methhoxychlor	30	0.1

Drinking Water Production

Food Act 1983 (Malaysia)

- Almost similar to WHO guidelines
- Higher requirements in a few parameters
- Being updated several times

Drinking water production

Food Act 1983 (Malaysia)

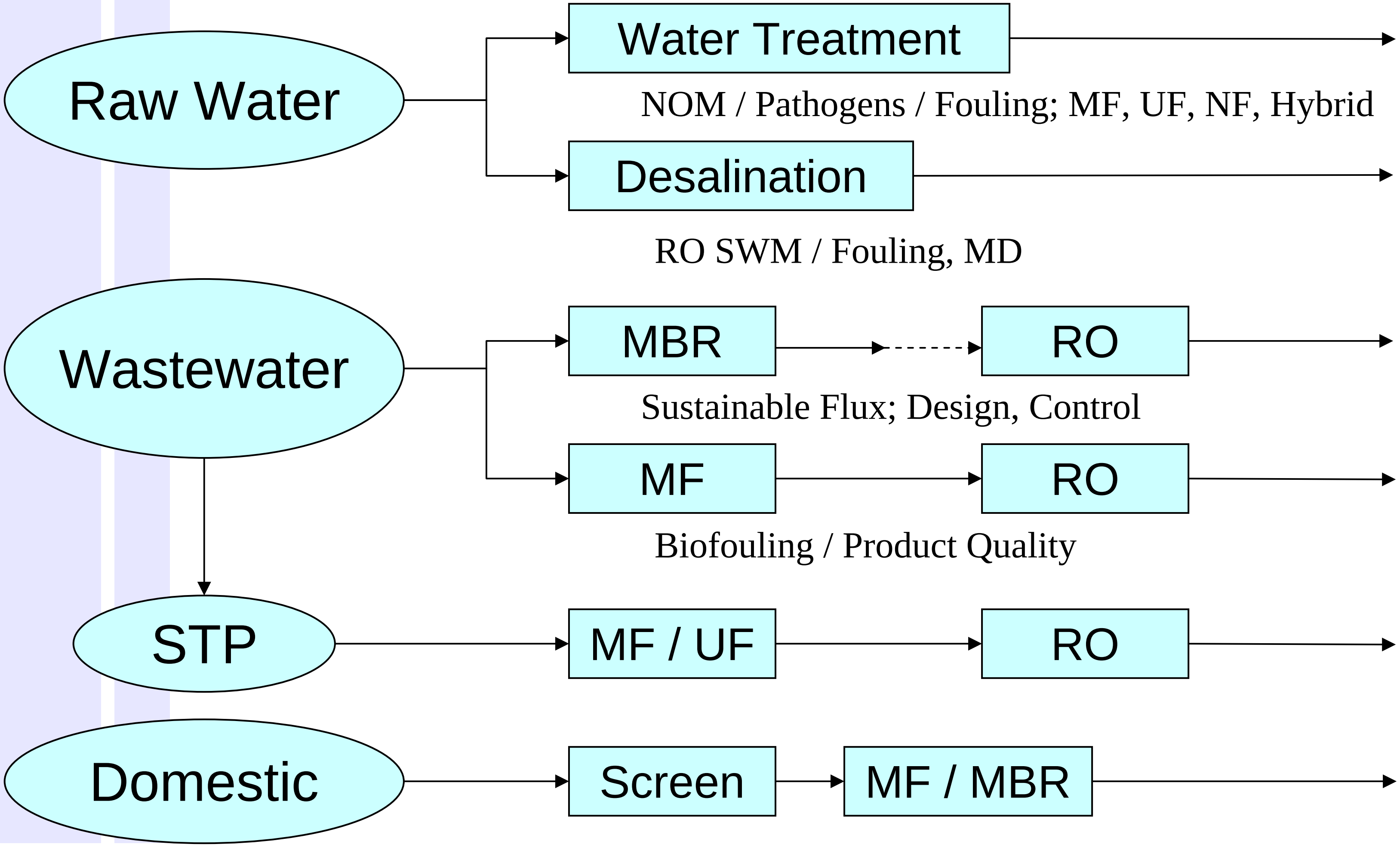
Compounds	Standard
Colour	15 Hazen
Turbidity	5 NTU
Aluminium	0.2 mg/L
Arsenic	0.05 mg/L
Cadmium	0.005 mg/L
Chloride	250 mg/L
Chromium	1 mg/L
Phenol	0.002 mg/L
Mercury	0.001 mg/L

Drinking water production

Food Act 1983 (Malaysia)

Compounds	Standard
Ferum	0.3 mg/L
Plumbum	0.05 mg/L
Magnesium	150 mg/L
Manganese	0.001 mg/L
Sodium	200 mg/L
Sulfat	400 mg/L
Zinc	5 mg/L
Residual chlorine	0.1 mg/L
Argentum	0.05 mg/L

Membrane technology



Conventional Water Treatment Processes

Process	Purpose
Aeration	Gasses, Fe, Mn, odor & taste removal
Coagulation	Solid/liquid separation
Flocculation	Solid/liquid separation
Sedimentation	Solid/liquid separation
Filtration	Solid/liquid separation
Disinfection	Bacterial removal

Advanced Water Treatment (1)

Oxidation	Organic, gasses, Fe, Mn, odor & taste removal
Coagulation	Solid/liquid separation
Flocculation	Solid/liquid separation
Sedimentation	Solid/liquid separation
Sand Filtration	Solid/liquid separation
Enhanced Oxidation	Organic removal
Activated Carbon	Taste & odor
Disinfection	Bacterial removal

Advanced Water Treatment (2)

Process	Purpose
Coagulation & PAC	Solid/liquid separation
Sedimentation	Solid/liquid separation
Ozonation	Organic, taste & odor removal
Sand filtration	Solid/liquid separation
Nanofiltration	Solid/liquid separation & NOM removal
Disinfection	Bacterial removal

Advanced Water Treatment (3)

Process	Function
Coagulation & PAC	Solid/liquid separation
Sedimentation	Solid/liquid separation
Microfiltration	Organic, taste & odor removal
Nanofiltration	Solid/liquid separation & NOM removal
Disinfection	Bacterial removal

Advanced Water Treatment (4)

Coagulation	Solid/liquid separation
IMF-PAC	Solid/liquid separation Organic, taste & odor removal NOM removal
Disinfection	Bacterial removal

Treatment Principles: Selective Barrier

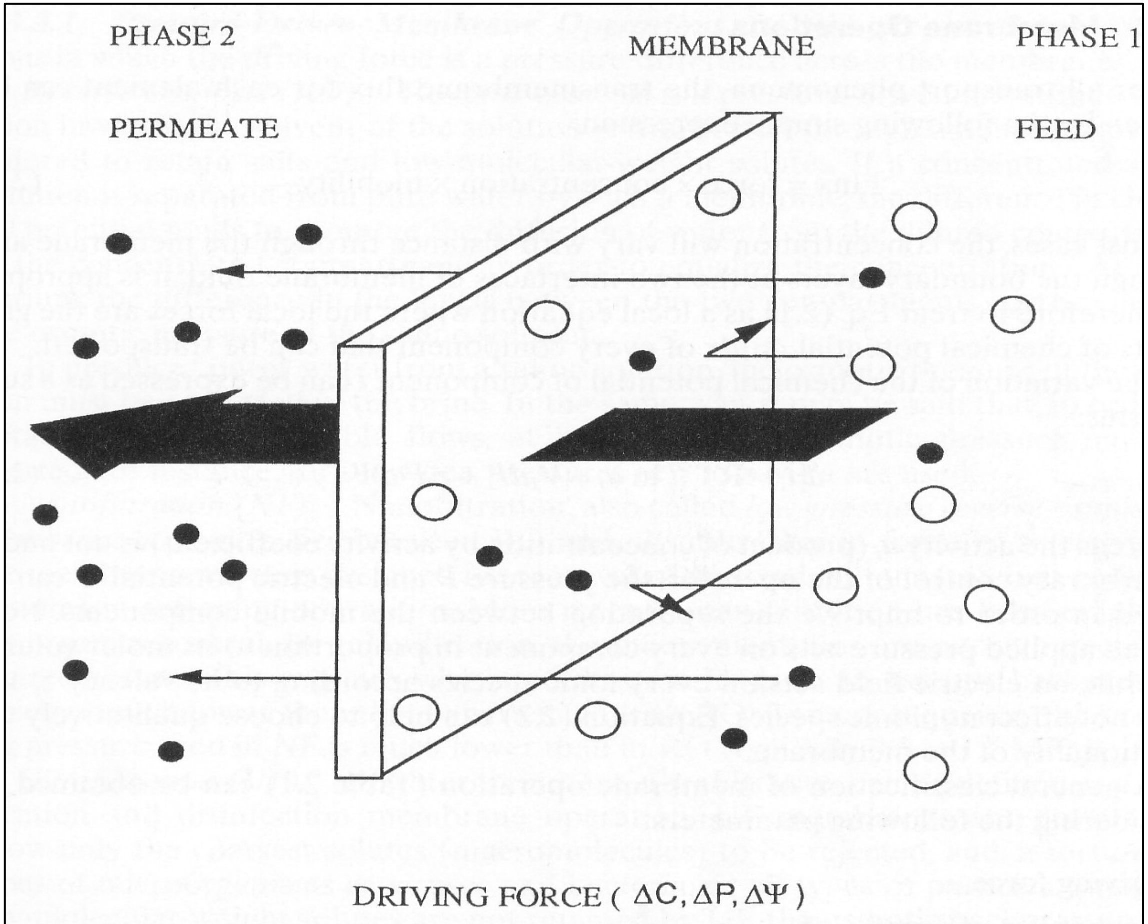


FIGURE 2.1 Definition of a permselective membrane.

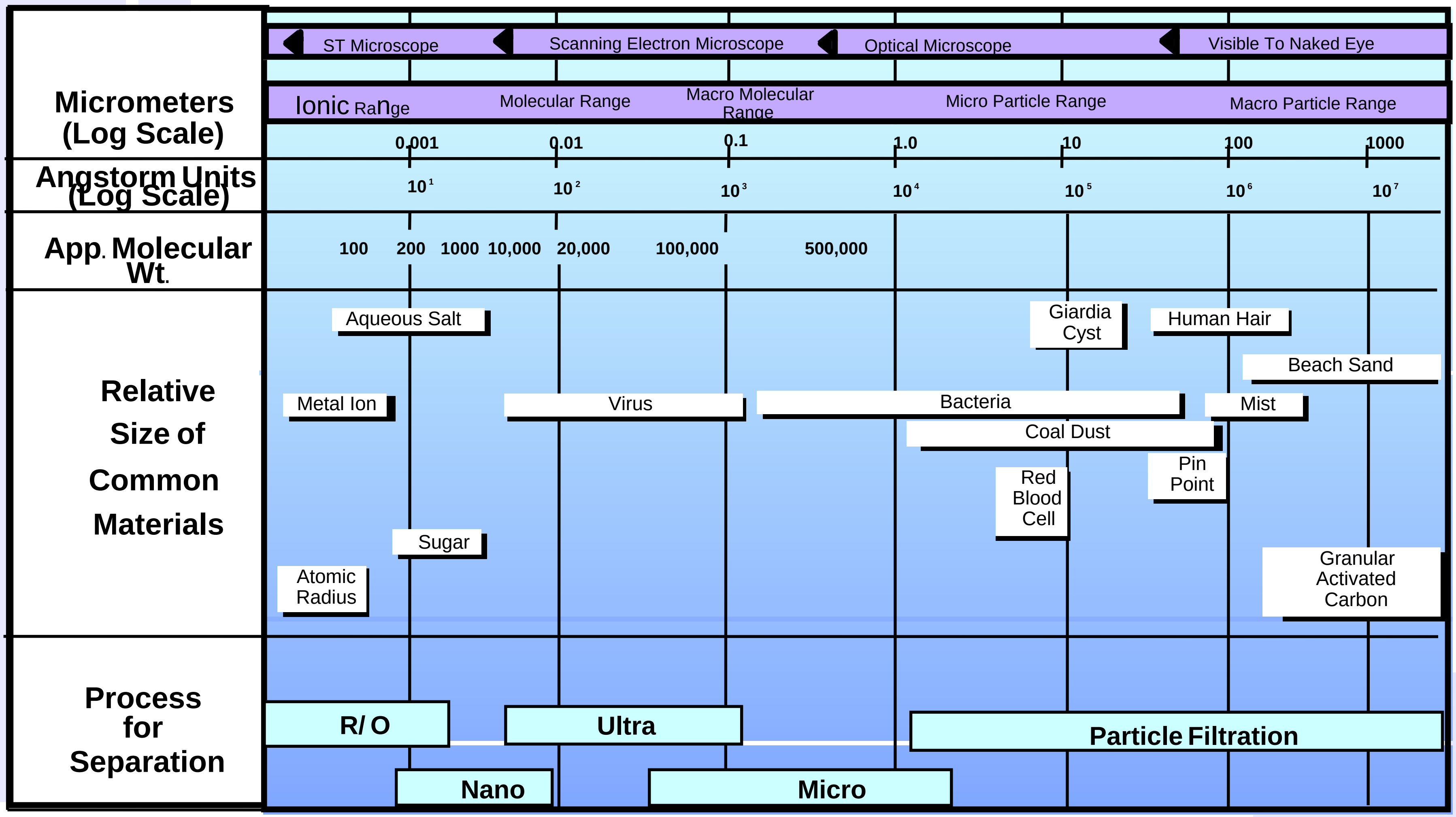
Target water pollutants, and technology options

Era	Pollutants	Solutions
1800s	Pathogenic bacteria	Sewer system
1900s	BOD, COD	Biological wastewater plants
1950s	Heavy metals, biodegradable substances	Treatment at source
1970s	Eutrophication	N and P control
1980s	Trace substances, carcinogens, flavor, taste	Activated carbon, membrane technology
1990s	CO_2, NH_4, N_2O, CFCs, NO_x, SO_x	Energy saving, photosyntetic bacteria, biotechnology, MBR
2000s	Endocrine disrupting chemicals (EDCs), eco-hazard	Membrane technology

Overcome cryptosporidium outbreak

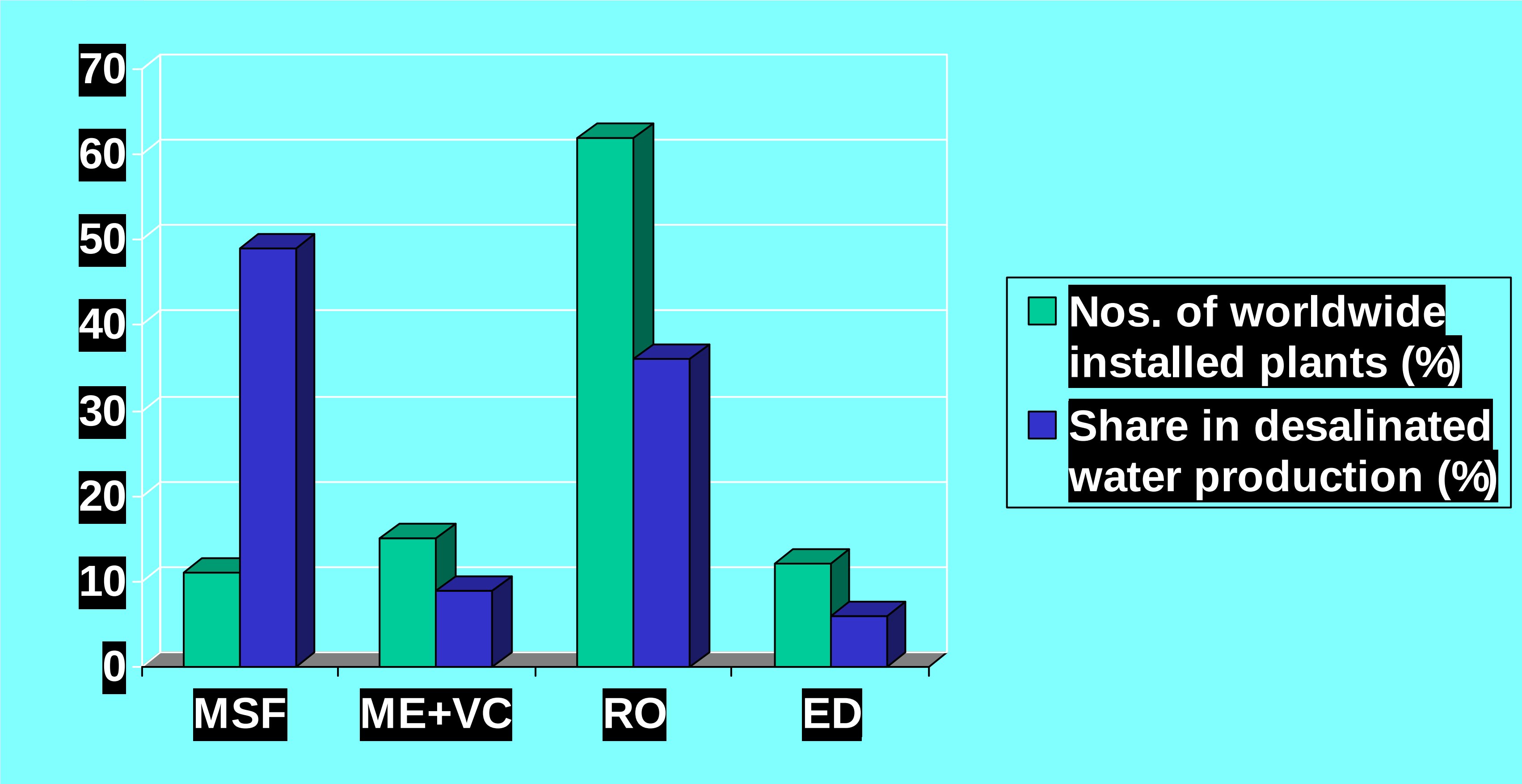
Membrane plant for water treatment, Ogose Town, Japan

Filtration Spectrum



Part 2:
Membrane Configurations

The trend of the past



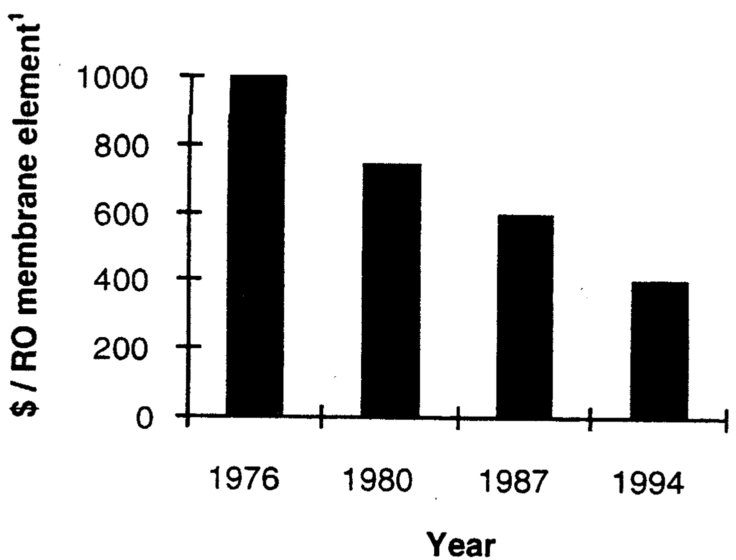
Installation of Desalination Technology, 1990-2000, by size (ref; IDA inventory)

Reality on membrane cost

Spiral-wound module trends (20 years)

Cost/Element down to 40%, Productivity up 200%

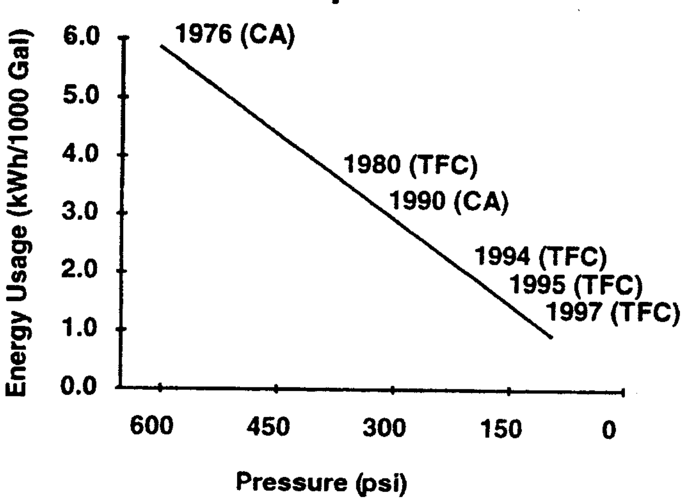
Declining cost of membrane elements



Source: Water Factory 21 municipal wastewater reclamation plant

[1] 8-inch spiral wound cellulose acetate membrane elements

Declining energy requirements for desalting municipal wastewater[1]



Source: Water Factory 21 municipal wastewater Adapted by C.Gabelich MWD

[1] Membranes operating at a nominal flux of 10.4 gfd at 20 °C on lime treated secondary effluent

Module Configurations

- Flat sheet membrane
- Tubular
- Hollow fibre
- Sprial wound

Based on specifications by manufacturers, consultants, system integrators

Module configurations

Considerations

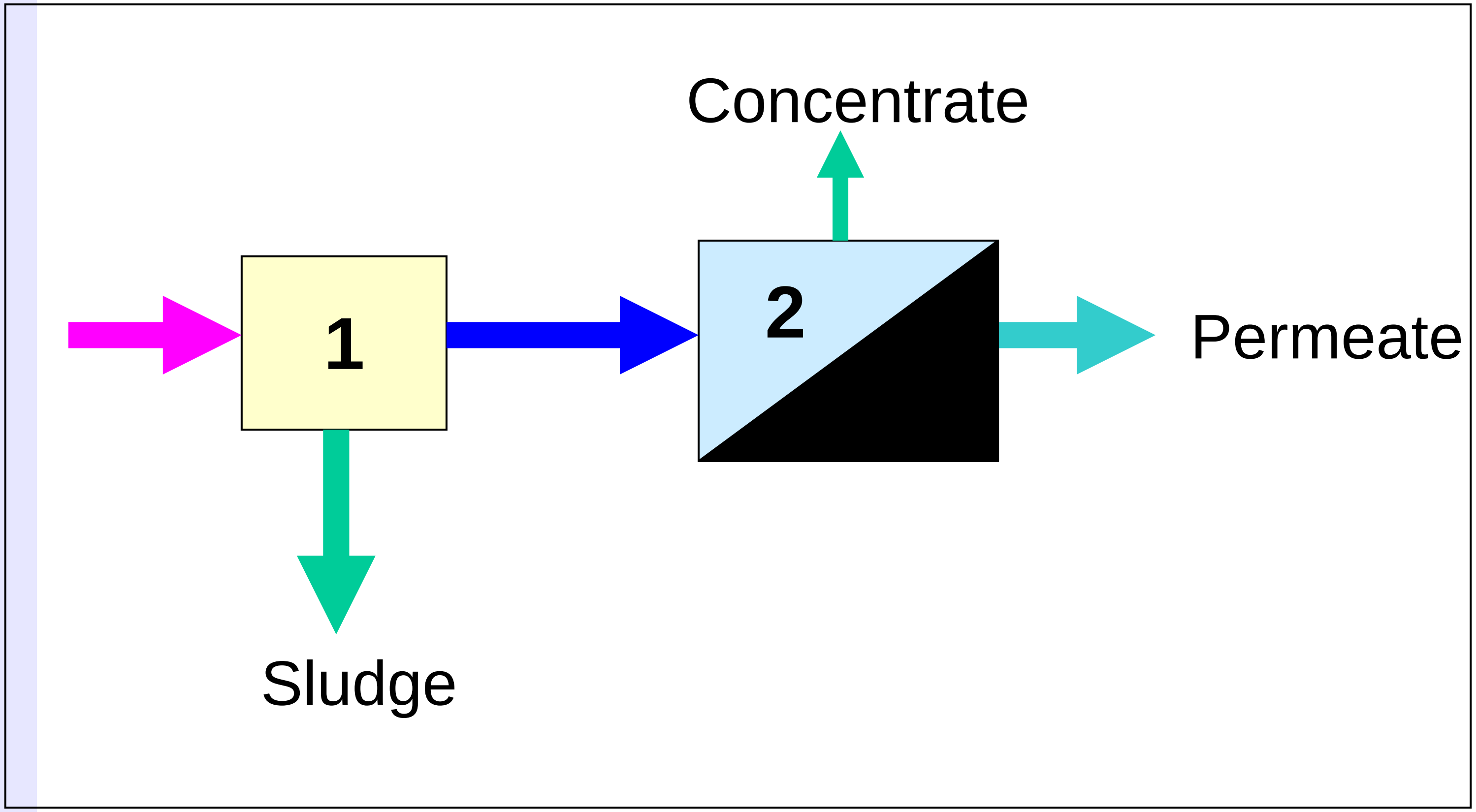
- Treatment objectives
- Manufacturers' specifications
- Size of operation
- Operating cost estimation (low OPEX?, high CAPEX?)
- Capital expenditure (low CAPEX, high OPEX?)

Part 3:
Membrane Systems

Physical separation

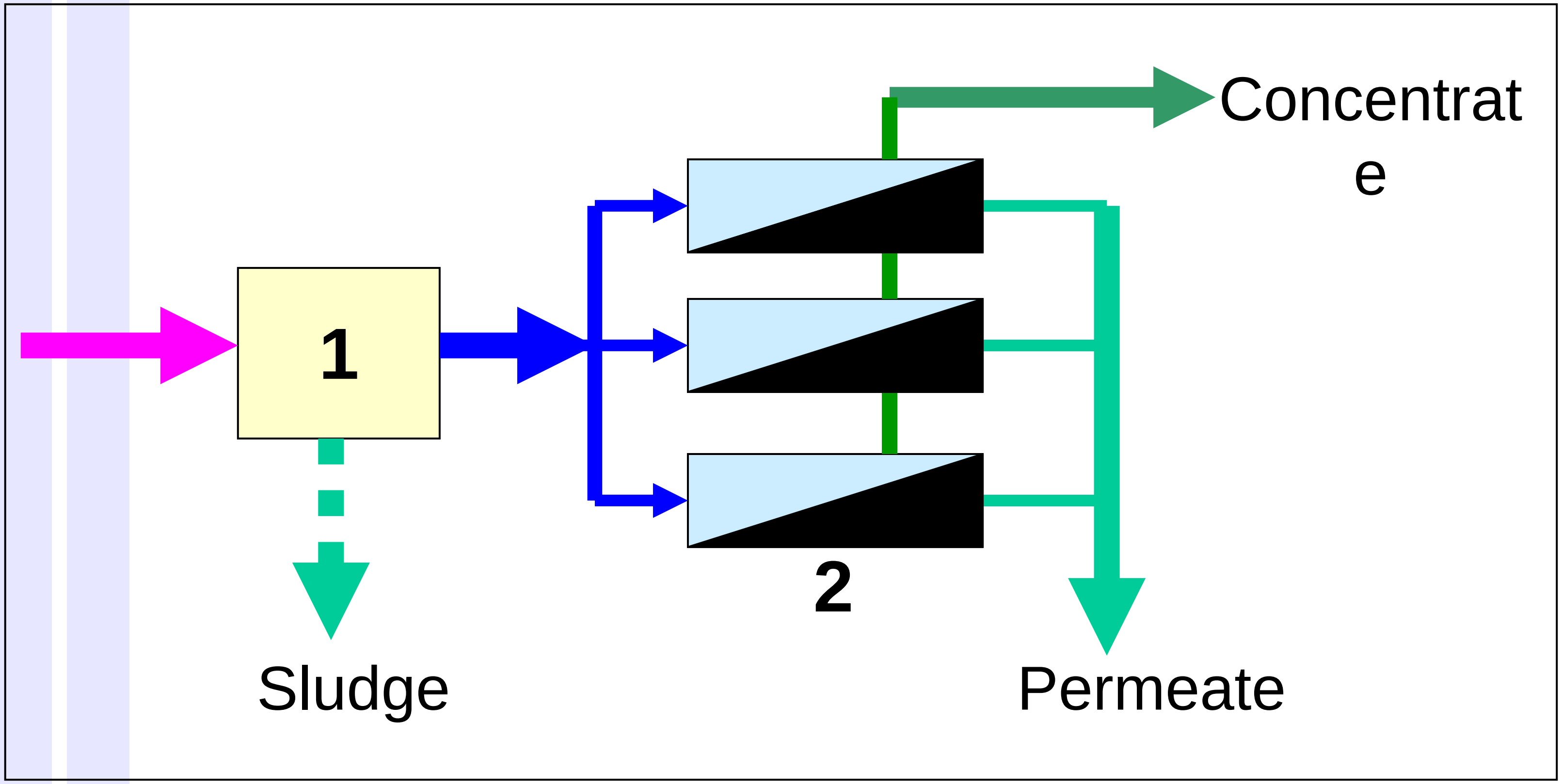
- Single membrane operation
- Multiple membrane operations
- Hybrid conventional treatment system + membrane operation

Single Membrane Operation



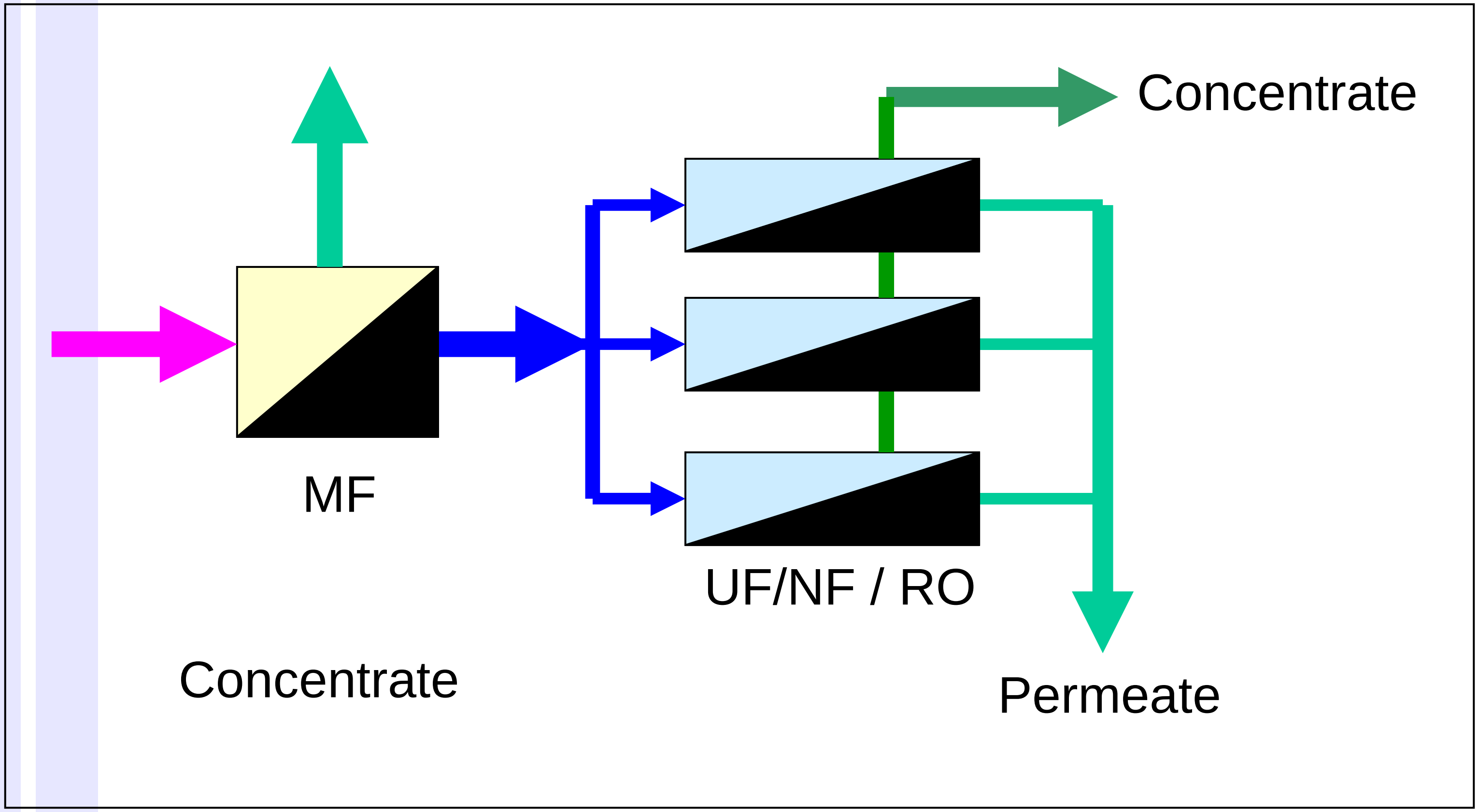
(1) Pretreatment unit (2) Membrane unit (s)

Single Membrane Operation



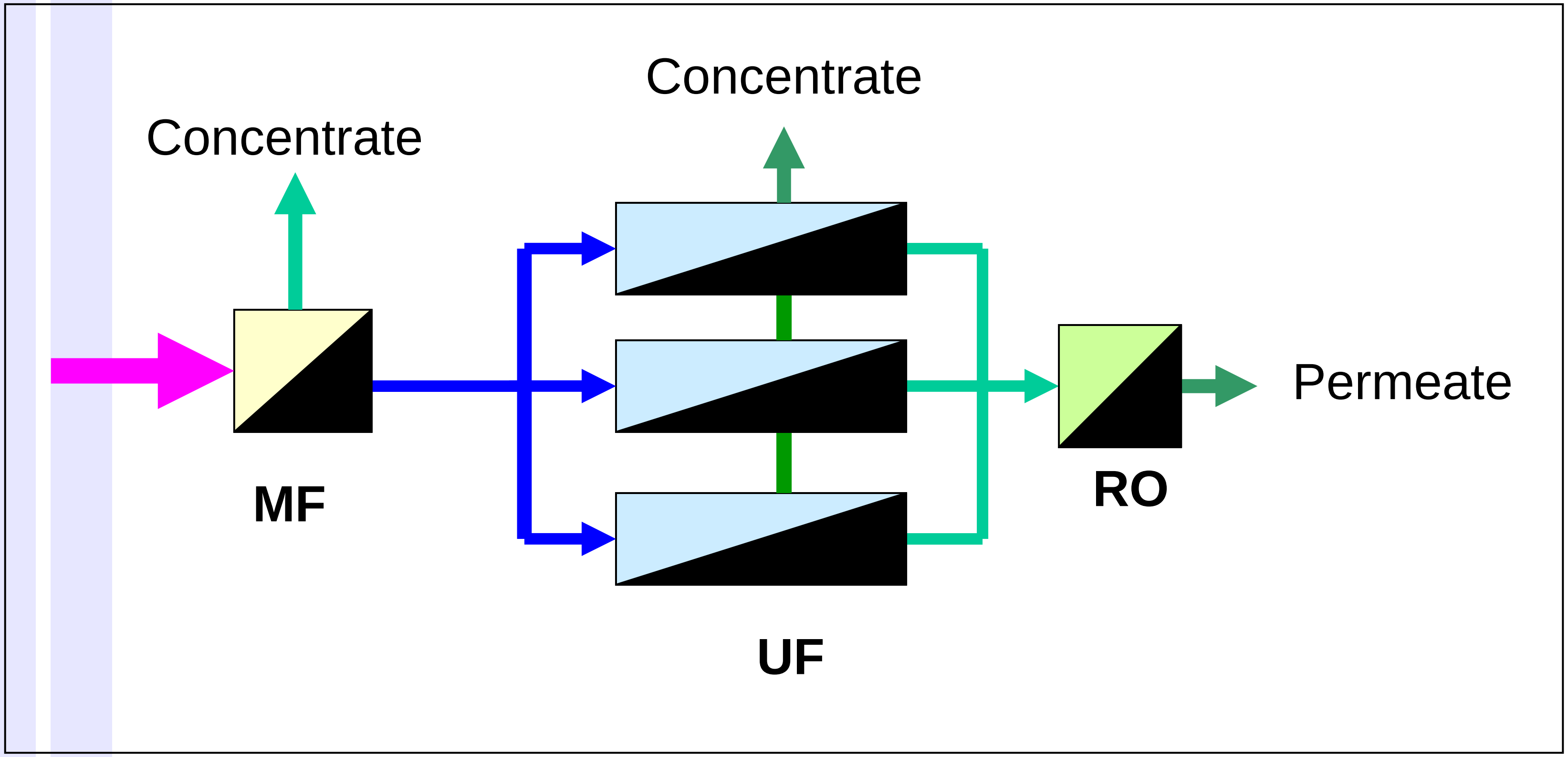
(1) Pretreatment unit (2) Membrane unit (s)

Multiple Membrane Operations



Normally, first with UF, followed by UF, NF and RO

Multiple Membrane Operations



Normally, first with UF, followed by UF, NF and RO

Part 4:

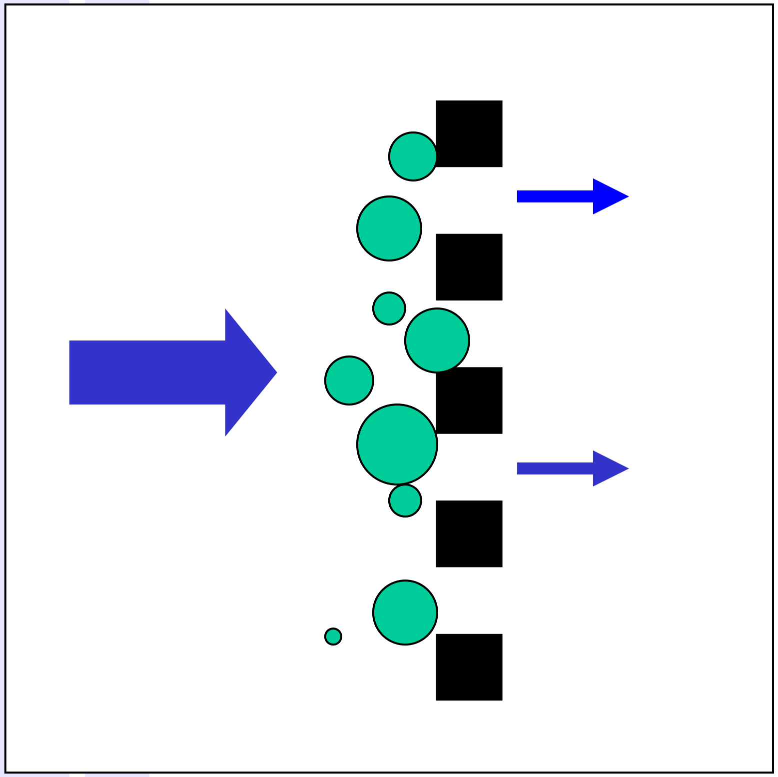
Microfiltration

Microfiltration

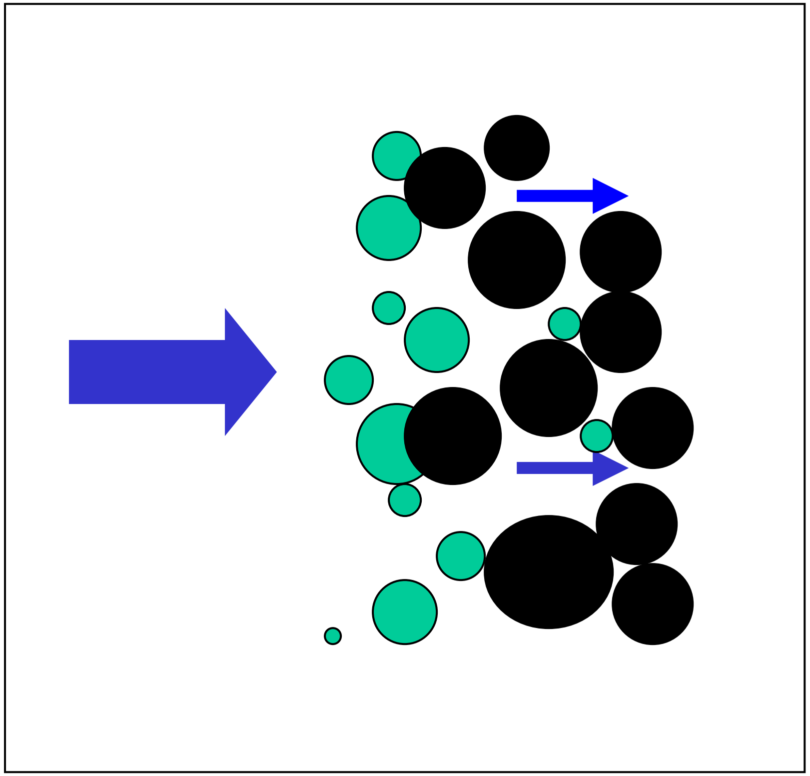
- Exact pore size is a matter of debate
- Generally – filterable of *0.02-10* micron
- Particles, colloids, microorganisms (incl. *bacteria and virus*)
- Larger flux compared to UF, NF or RO
- Separation based on *sieving process* (or also known as surface filtration)
- Opposite to surface is depth filtration
- Operation pressure: 50 to 500 KPa

Microfiltration

Surface filtration vs Depth filtration



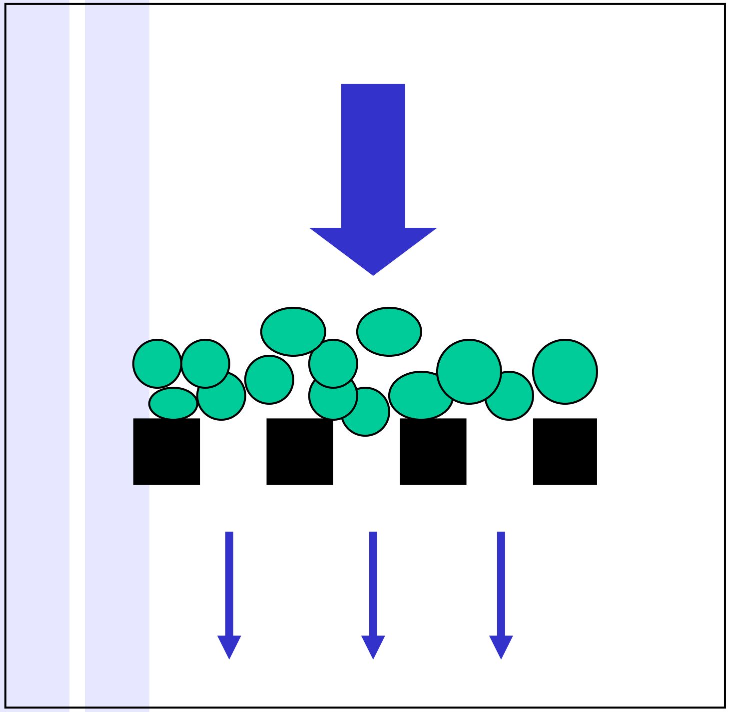
Surface filtration



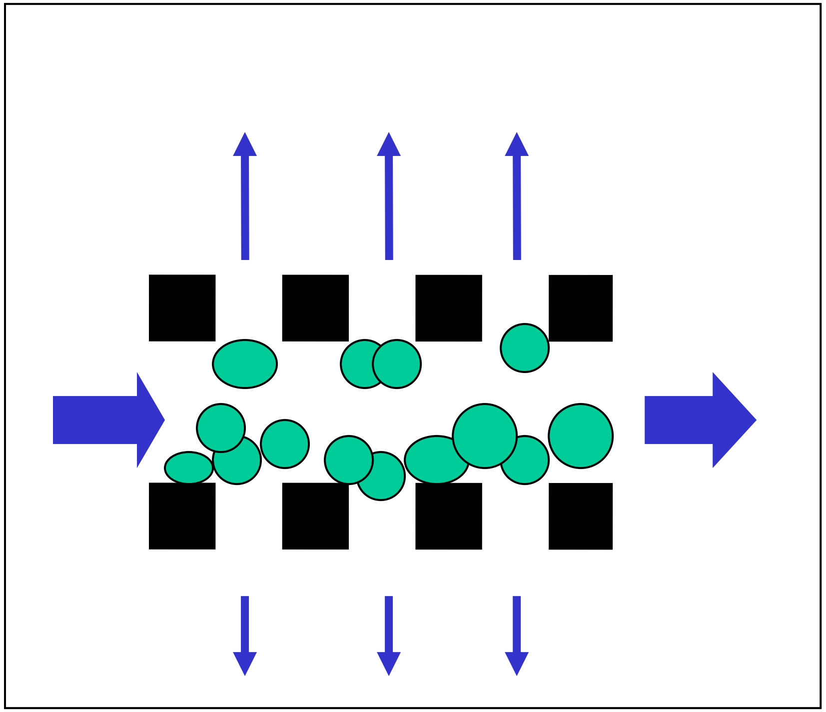
Depth filtration

Microfiltration

Deadend vs Crossflow filtration



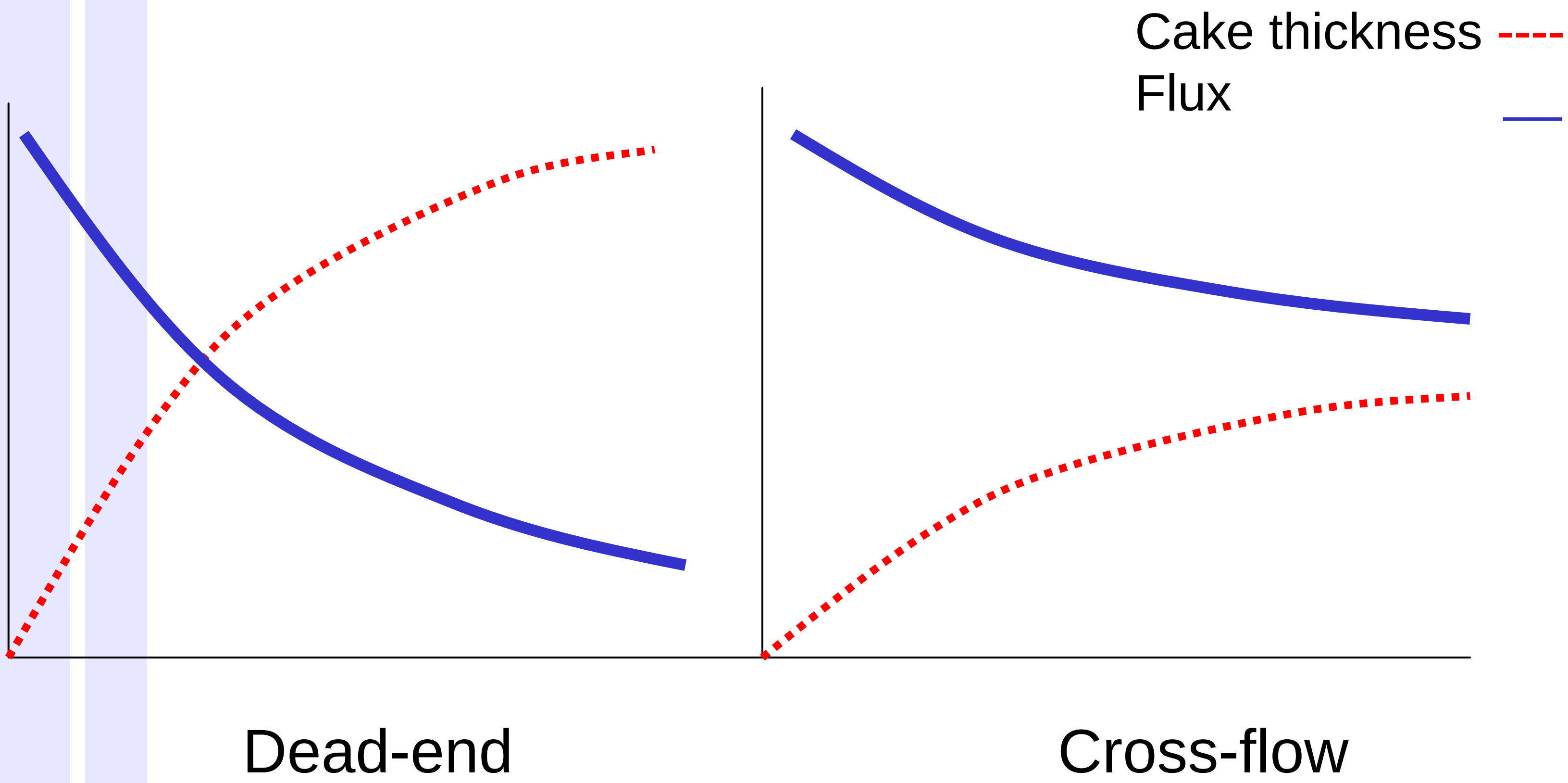
Deadend filtration



Crossflow filtration

Microfiltration

Deadend vs Crossflow



Microfiltration

Fouling and flux decline

Internal membrane fouling

Attachment of materials within the internal pore structure of membrane, or directly to membrane surface due to adsorption, precipitation, pore plugging, particulate adhesion etc.

External cake fouling

Formation of stagnant cake layer on the membrane surface due to concentration-polarization as the material being filtered is carried to the membrane by permeate flow and is then rejected by membrane

Membrane permeability

Permeability = (filtration rate ÷ area) × pressure difference

- Testing before design stage
- Benchmarking procedures
- Testing before commissioning
- Testing before fouling studies

Microfiltration systems

Components

- Piping systems
- Pumps
- MF modules
- Pressure gauges
- Feeding and permeate tanks
- Control systems
- Pretreatment facilities

Process parameters for design

- **Fluid to be filtered**
  - State-liquid or gas? Composition
  - Quantity, viscosity, temperature etc.
- **Suspended materials to be retained**
  - Composition, liquid or solid? Concentration
- **System considerations**
  - Specifications of process and materials
  - Constancy / variability of feed
  - Need for sterile conditions?
  - Time for processing?
  - Batch or continuous processes?

Applications of Microfiltration

- Potable water production (colloid & bacteria removal)
- Mineral processing
- Enhanced contacting (ion exchange, activated carbon)
- Bioseparation
- Syringe filters

Clarification

Ogose Town Membrane Plant, Japan

Design criteria	Values / specifications
Design flow	4000 m^3/day
Membrane	4UF, 2 MF
Recovery rate	99%
Pretreatment	Coagulation, rapid sand filter
Backwash	Pressurize water & air scrubbing

Immersed Membrane Filtration

Microfiltration / PAC System

- Similar membrane used in MBR
- Reaction zone for
  - adsorption
  - biodegradation
  - coagulation
- Flexibility in operation
  - operation at high SS concentration
  - adapt type & age of suspension as required
  - Single-step process

Immersed Membrane Filtration

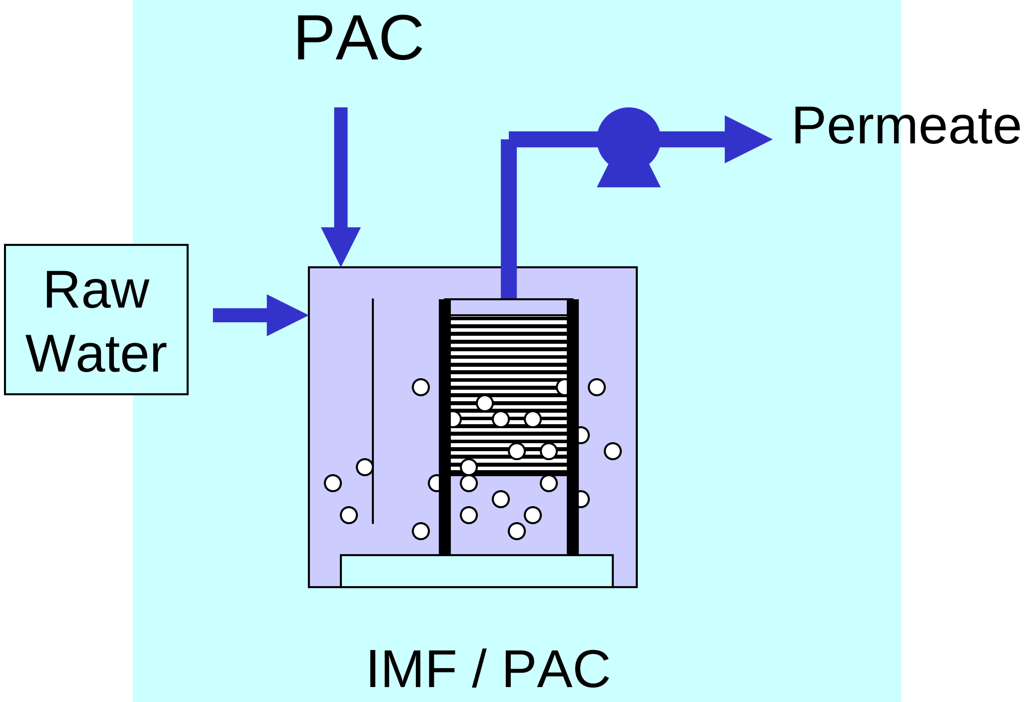
Microfiltration / PAC System

- NOM & SOCs removal
- Biological removal of BDOC
- Reduced sludge volumes (0.1% of treated water flow rate)
- Absolute containment of PAC within the system independent of process conditions

Operating Principle

MF / PAC System

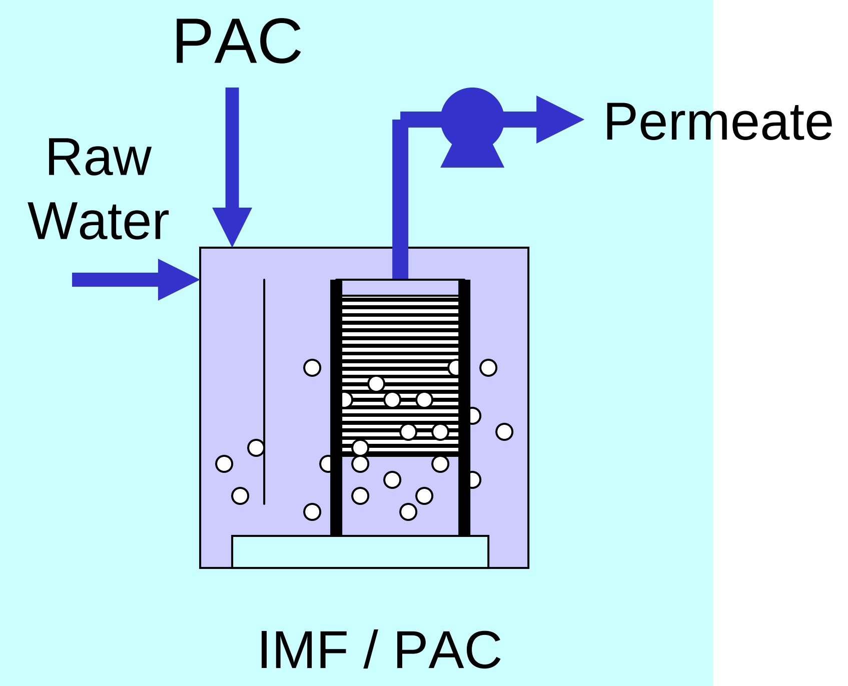
- Hollow fiber or plate & frame
- Outside-in mode
- 2 reaction basins:
  - (a) Reaction zone
  - (b) Permeate side
- Aeration is used to:
  - (a) Creating turbulence
  - (b) Avoid PAC sedimentation



Operating Principle

Microfiltration / PAC System

- Optimal & cost-effective utilization of PAC by allowing PAC aging inside the completely mixed reaction zone
- Optimal mixing & contact between water & PAC for maximum effectiveness



Operating principle

Microfiltration / PAC System

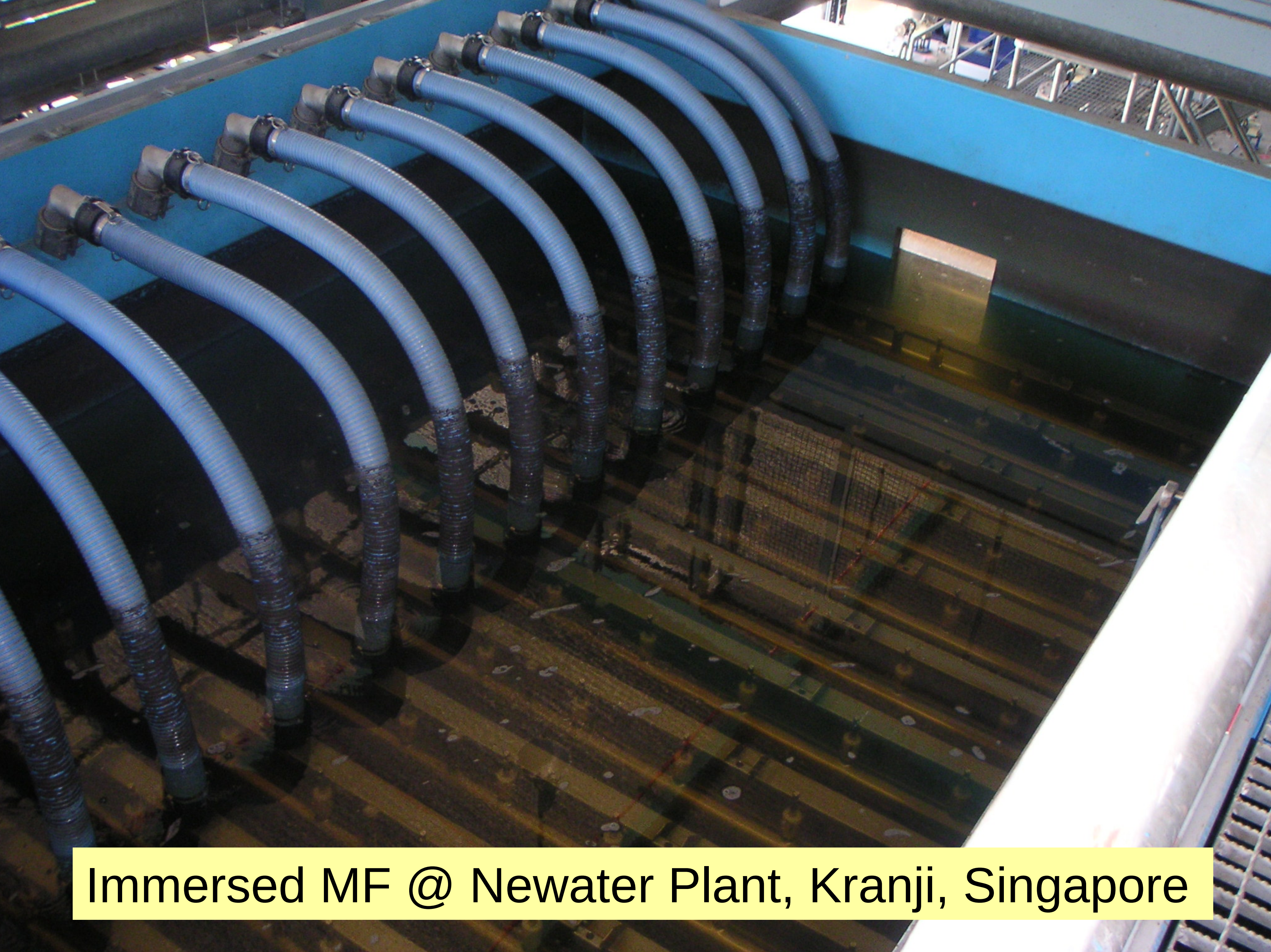
- PAC replacement is adaptable to the feed water quality with batch replenishment following procedure:
  - One a day a fraction of PAC slurry is purged to keep PAC slurry concentration stable in reactor.
- A replacement rate ‣ AGE
- Age = average residence time of particles inside reaction zone

$$Age = \frac{V_d}{V_R}$$

V_d = daily purge volume
V_R = reaction zone volume

$$D = \frac{M}{age \times Q_D}$$

D = PAC dosage rate
M = PAC in slurry
Q_D = daily flow rate



Immersed MF @ Newater Plant, Kranji, Singapore

Part 5:

Ultrafiltration

Ultrafiltration

Introduction

- Sieving process for separation (similar to MF)
- Almost similar pressure range as MF
- Major difference with MF: pore size (MF > 0.1μm)
- For water treatment, UF is used as clarification and disinfection operation, MF as treatment
- Remove all types of bacteria and virus
- Operating pressure: 50 to 500 KPa

Part 6:
Reverse Osmosis

Reverse Osmosis

- RO is a pressure-driven operation in which the solvent of the solution is transferred through a dense membrane tailored to retain salts ad low-molecular-weight solutes.
- If a concentrated saline solution is separated from pure water by RO, the difference in chemical potential tends to promote the diffusion of water from the diluted compartment to the concentrated compartment in order to equalize the concentrations.

Reverse Osmosis

- At equilibrium, the difference in the levels between the 2 compartments corresponds to the osmostic pressure of the saline solution.
- To get economical and viable flow, at least twice the osmotic pressure must be exerted
- For sea water, pressures of 5 to 8 MPa are used

Nanofiltration

(Also known as low-pressure RO)

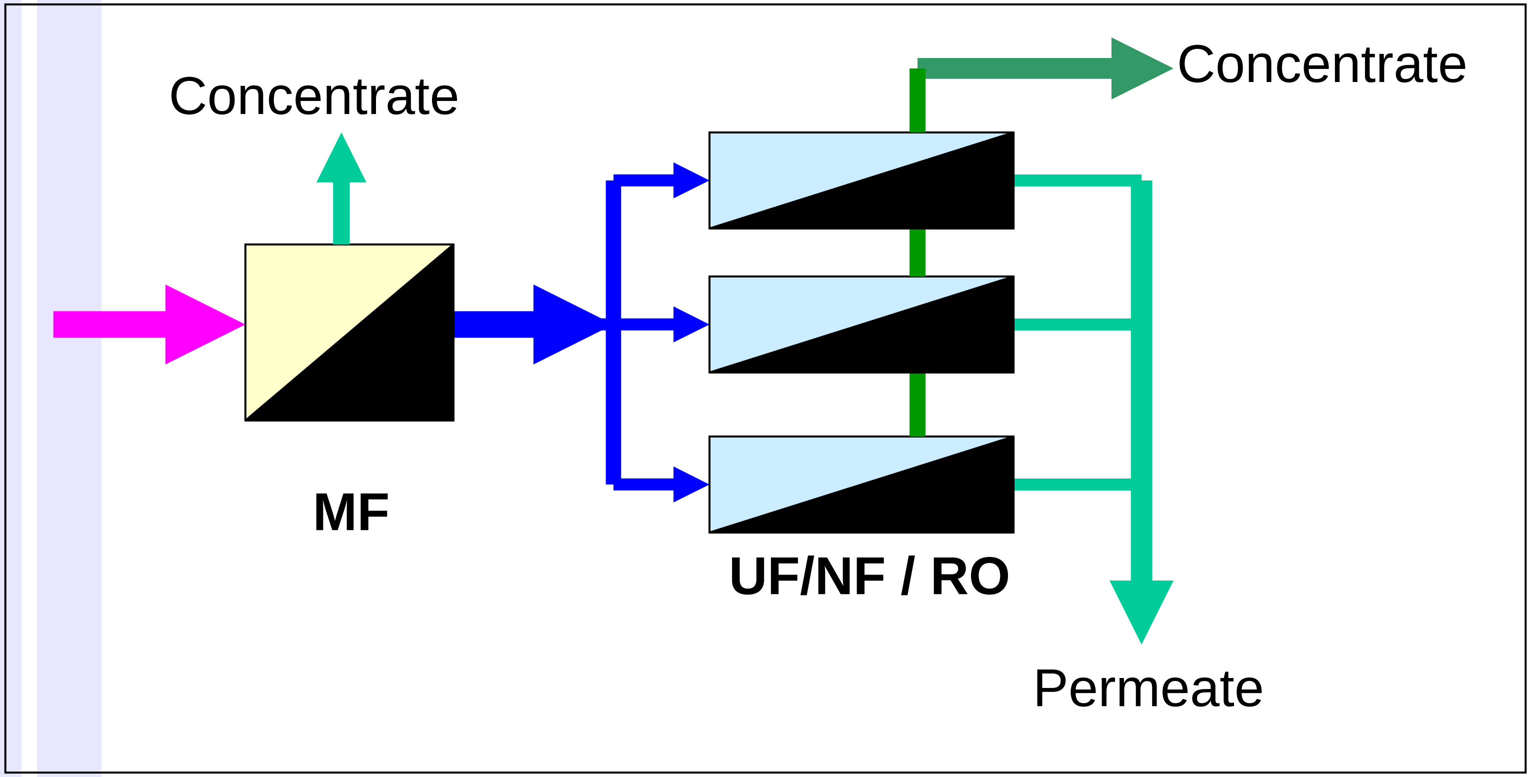
- Lies between RO and UF in terms of selectivity
- Removal of multivalent ions and organics
- Monovalent are poorly rejected (requires RO)
- NF leads to osmotic backpressure which is much lower than RO
- Pressure: 0.5 to 1.5 MPa

Applications of Nanofiltration

(Also known as low-pressure RO)

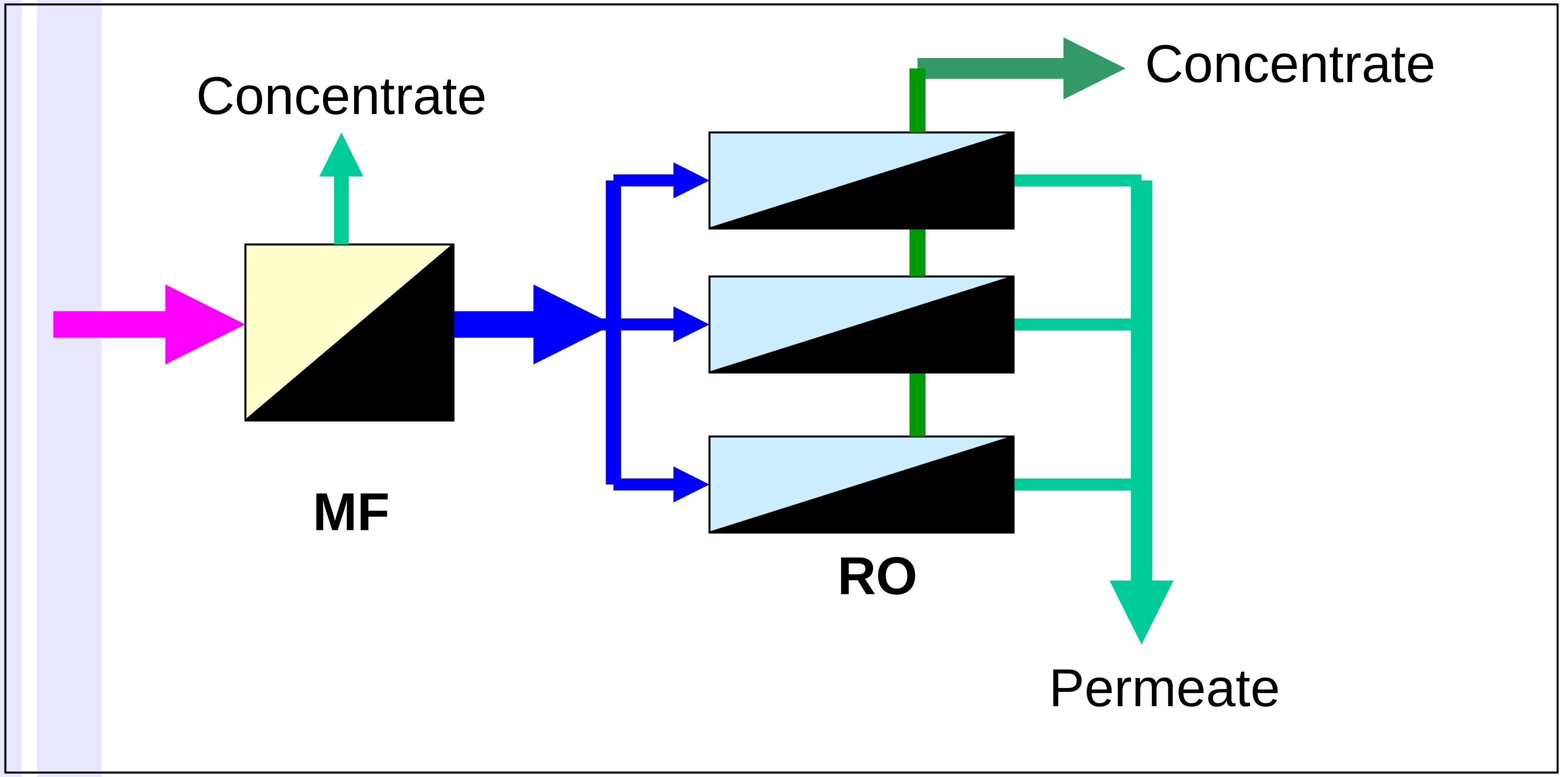
- Water softening
- Removal of organic matters, esp. NOM
- Removal of multivalent ions
- Desalting of organic reaction products
- Removal of arsenic and other metals
- Removal of endocrine disrupting chemicals

Multiple membrane operations for surface water

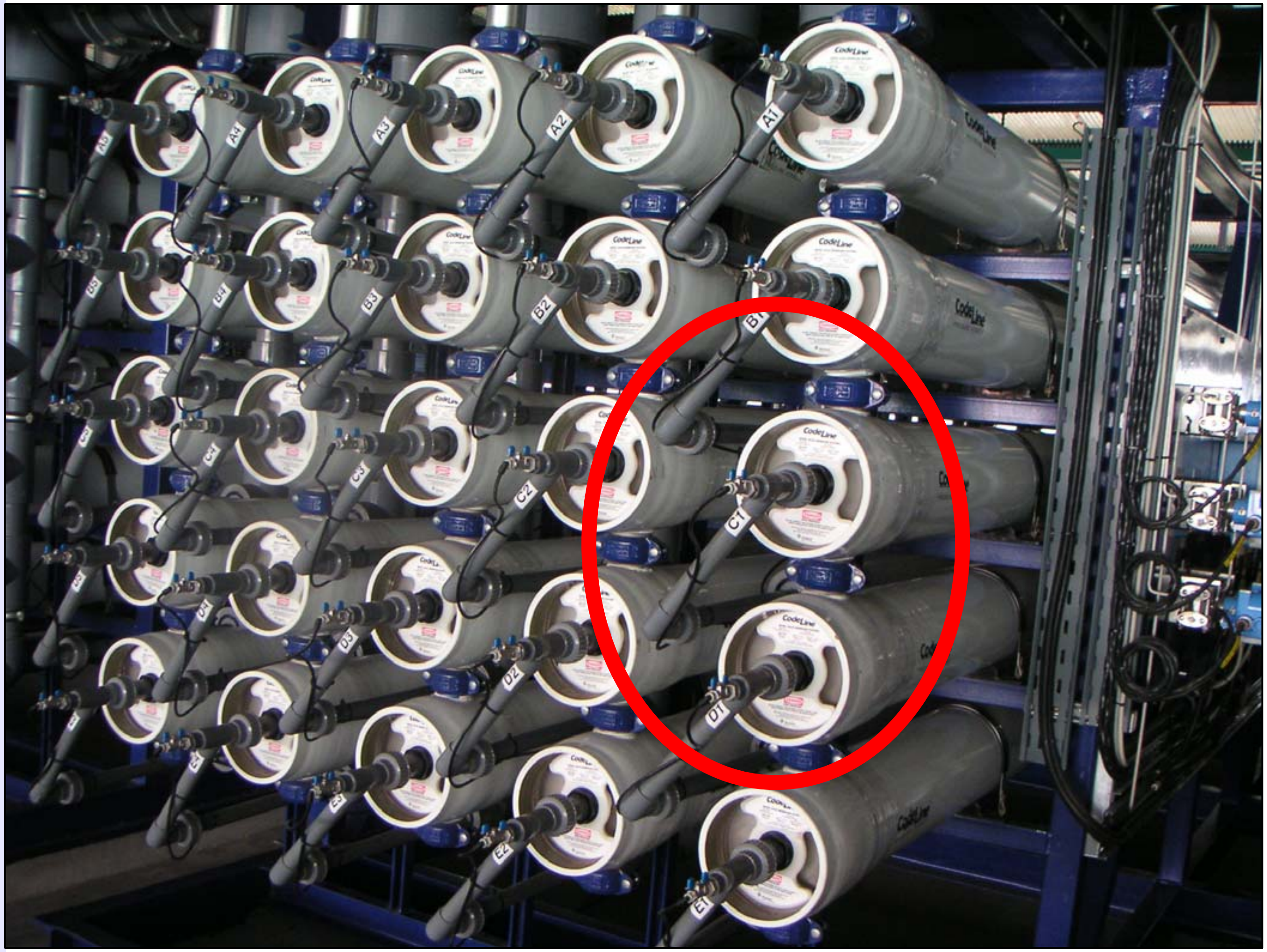


Normally, first with MF, followed by UF, NF and RO
(depends on the treatment objectives and quality of feed water)

Multiple membrane operations for seawater



Normally, first with MF, followed RO



Conclusions

- Membrane technology is well accepted in high quality of drinking water production
- Membrane technology is growing fast and very instrumental for the protection of public health and consumers' needs

Future directions

- Membrane technology will be central in public water production – EDC, heavy metals etc.
- Membrane is to be a household technology in many industries for process water treatment, waste recycling and cleaner production
- Membrane vs Pollution??
- Membrane to be <u>the</u> option for upgrading of the existing water treatment facilities