Lecture 3: Back to Basic 2

Membrane Module Configurations, Classifications, Types and Systems

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Presentation Menu

Part 1: Module configurations

Part 2: Membrane classification

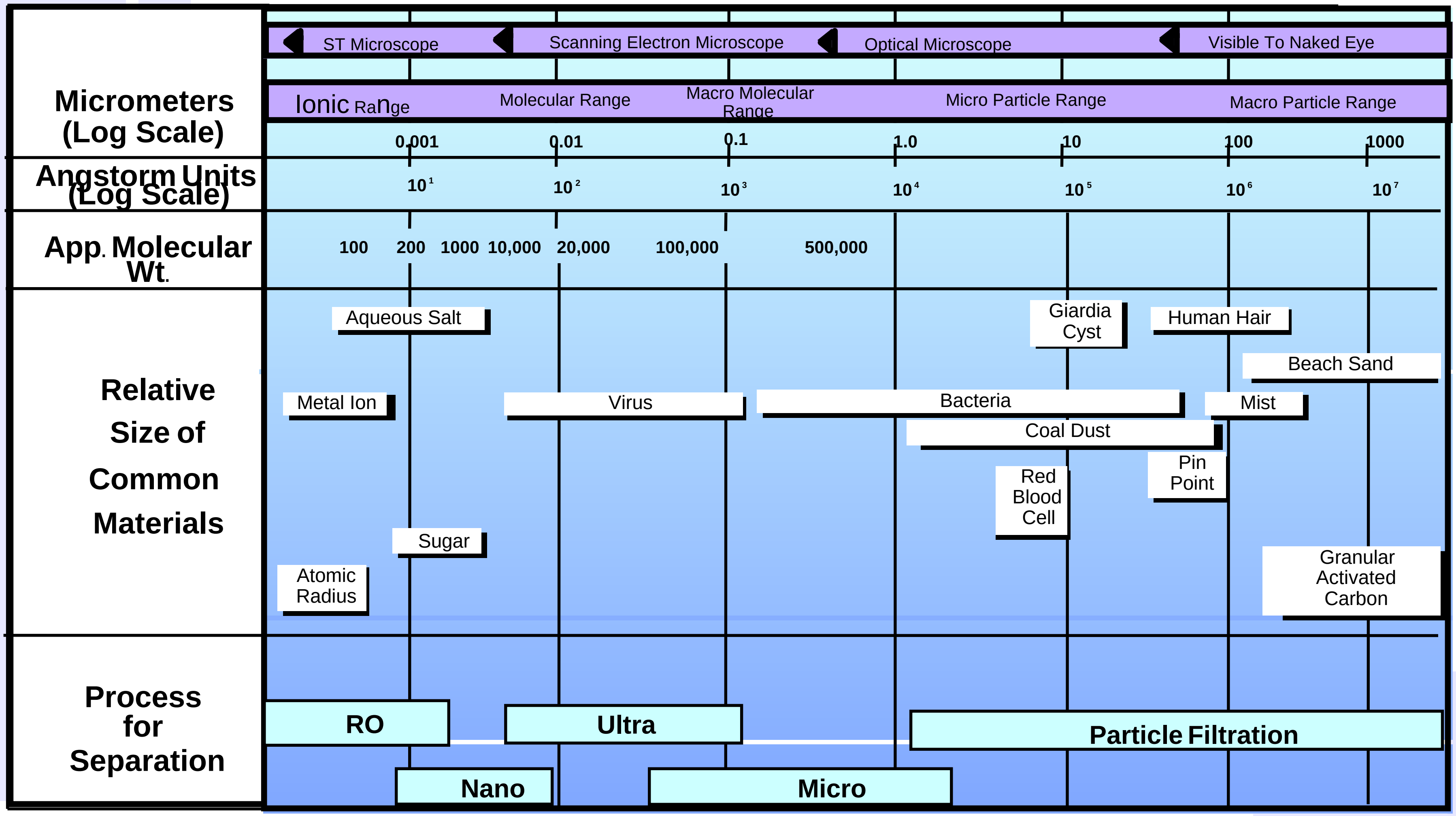
Part 3: Membrane types

Part 4: Membrane systems

Part 5: Membrane design using WASDA

Spiral wound configuration

Filtration Spectrum



Part 1:

Module Configurations

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

Objectives of Module Configurations

- To ensure sufficient circulation of fluid to be treated
- To limit phenomena of concentration polarization & particle deposit
- Product compact module ➔max A/V
- Avoid leaking between feed and permeate compartments

Basic requirement: Module design & development

- Easy to clean (hydraulic, chemical & sterilization)
- Easy to assemble and disassemble
- Low hold-up volume

Module Configurations – Flat sheet

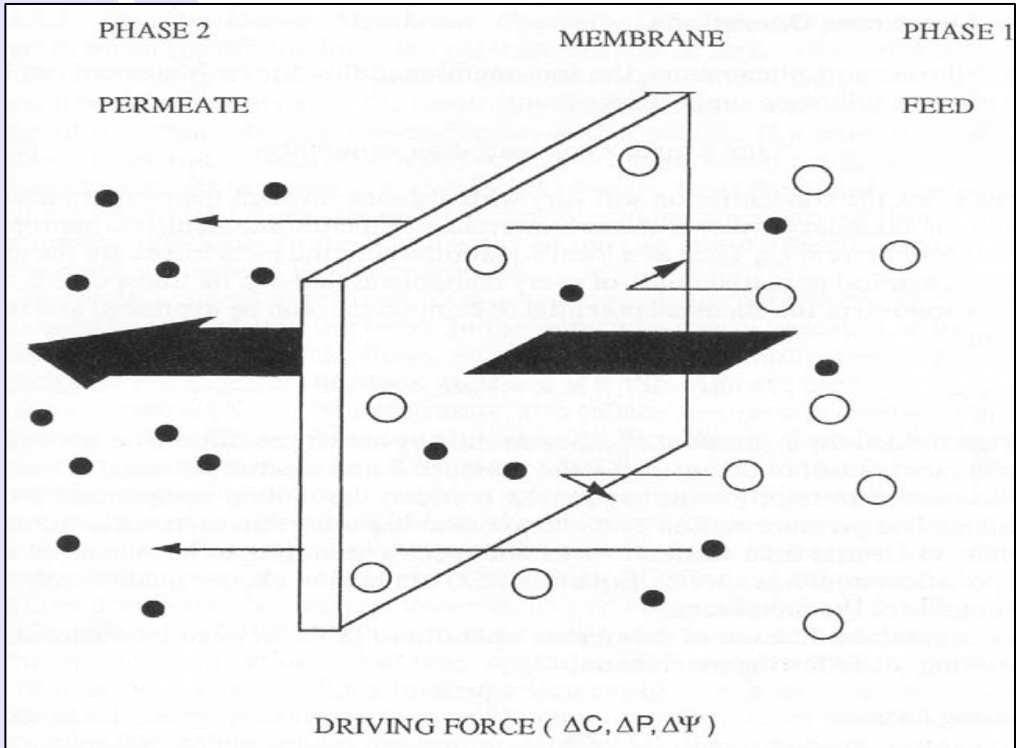
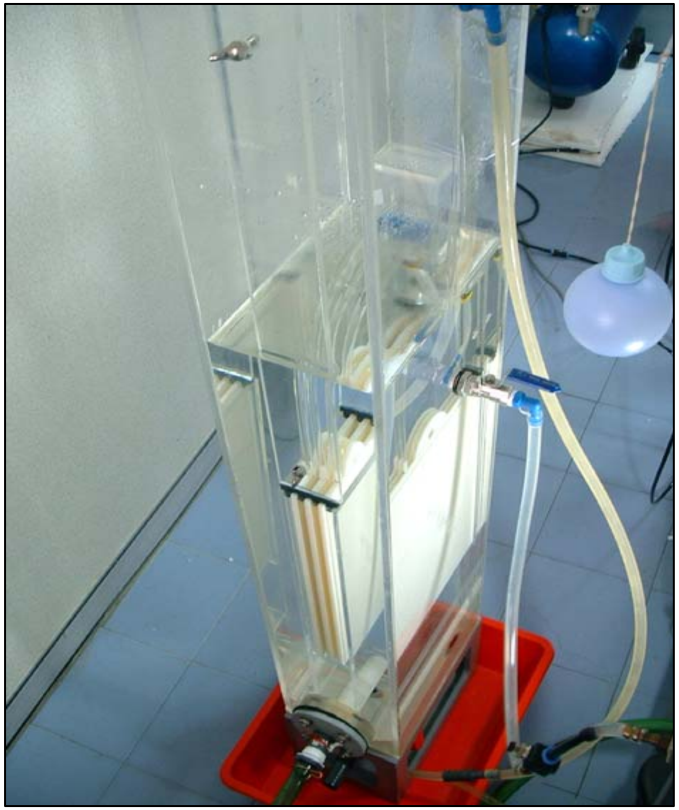


FIGURE 2.1 Definition of a permselective membrane.



Module Configurations – Tubular

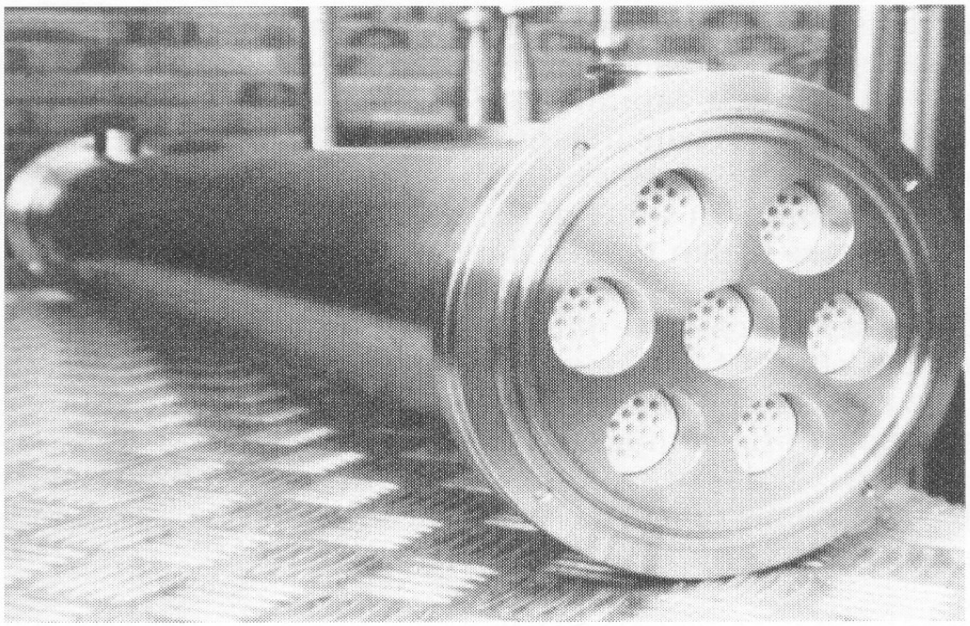
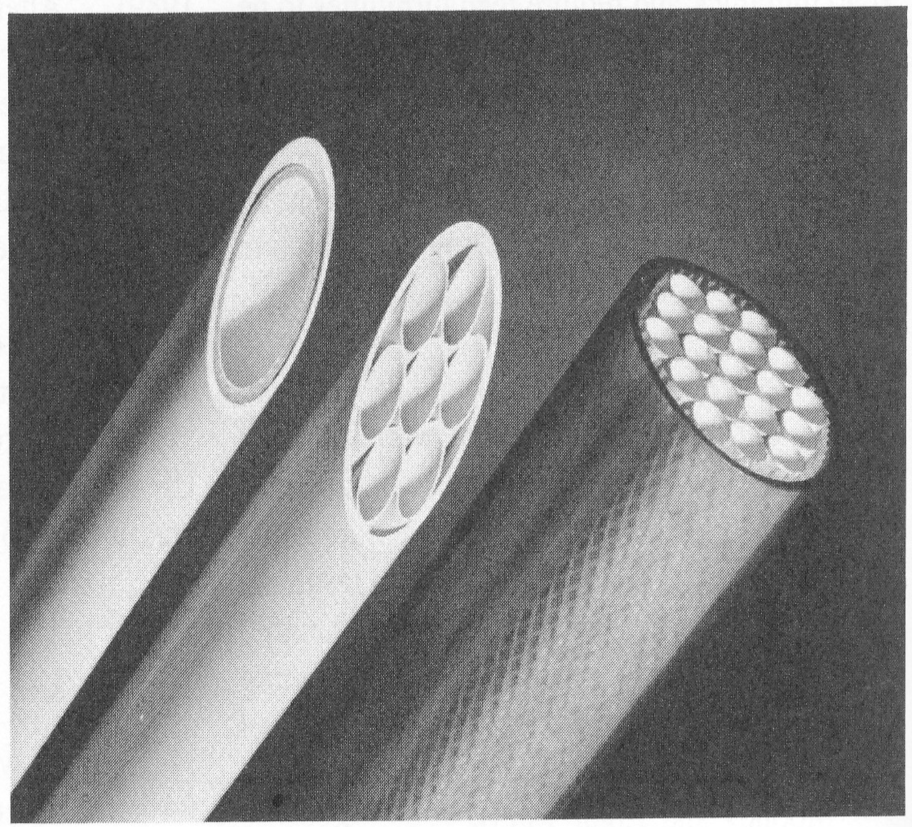


FIGURE 10.10 Example of a tubular ceramic membrane module. *(Kerasep-Techsep.)*

Module Configurations – Tubular

FIGURE 29–2. Cutaway view of various tubular systems. Tube diameters are 0.5 to 1 in. Membranes are cast into support tubes within PVC housings. (Courtesy of J. L. Short, Koch Membrane Systems.)



Membrane Configuration – Hollow Fibre

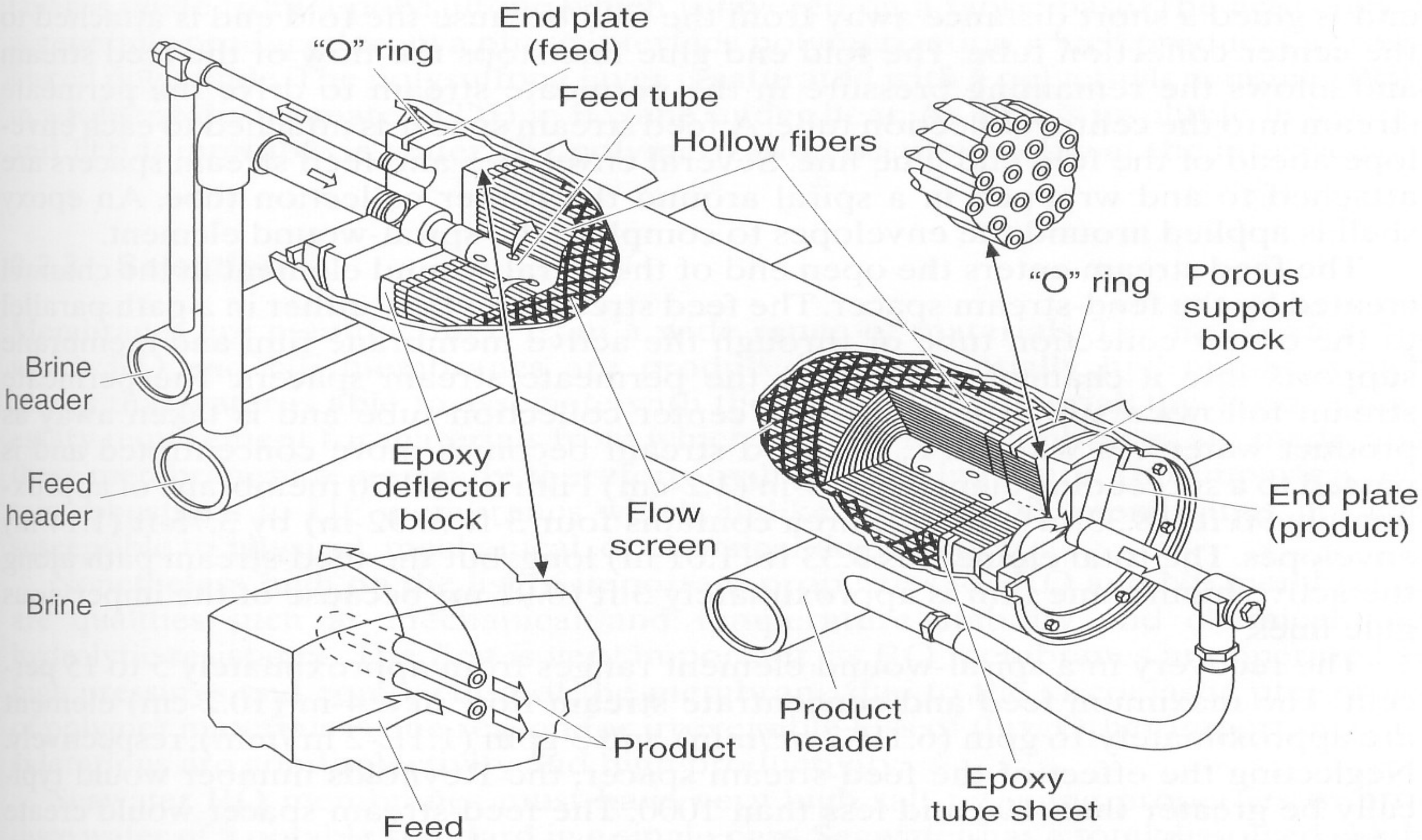
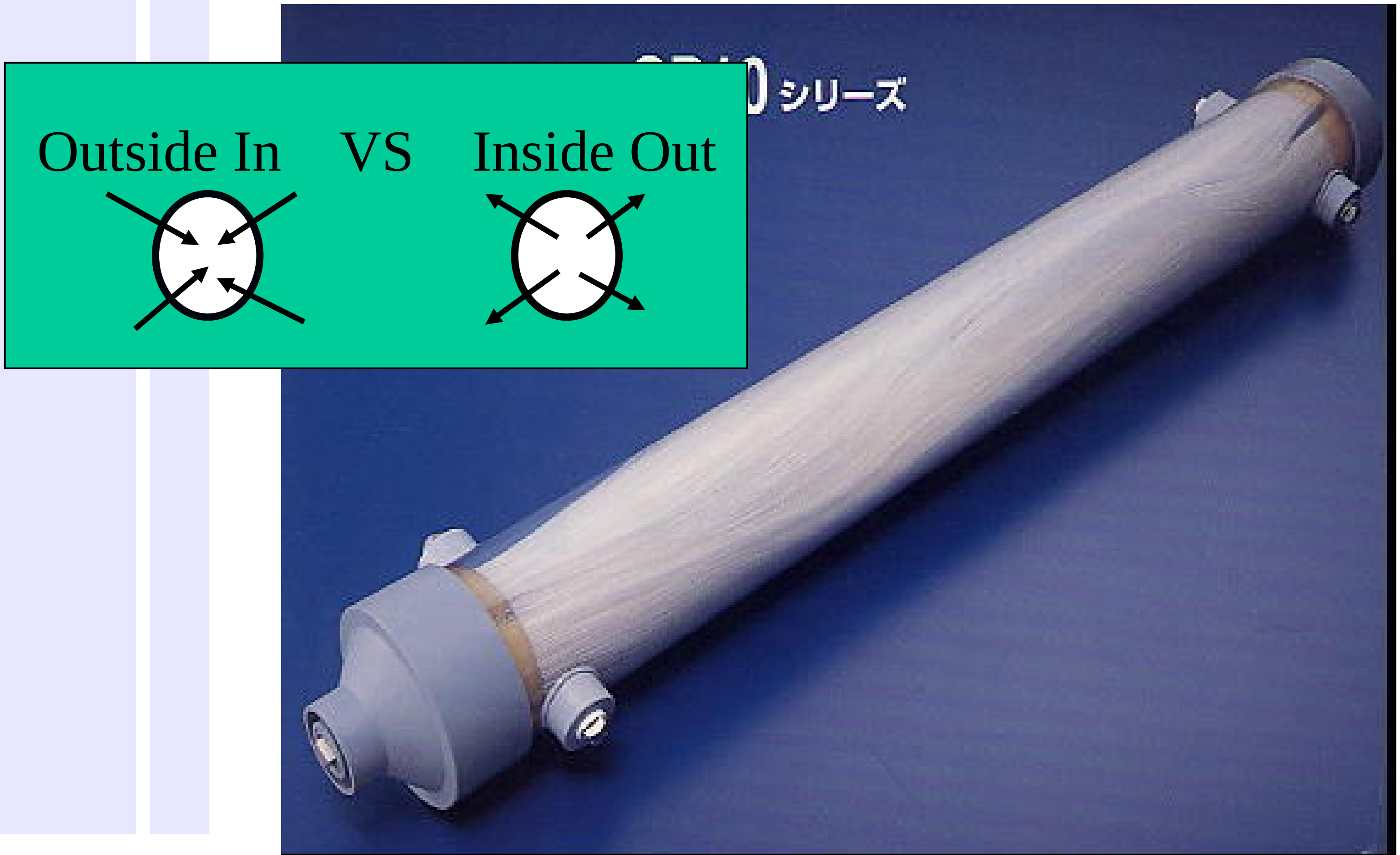


FIGURE 9.1 Diagram of a hollow fine-fiber reverse-osmosis membrane element.

Module Configurations – Hollow Fibre

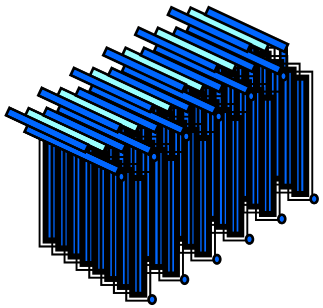


Membrane Configuration – Hollow Fibre

(ZeeWeed® Modules)

60 m^2 per module

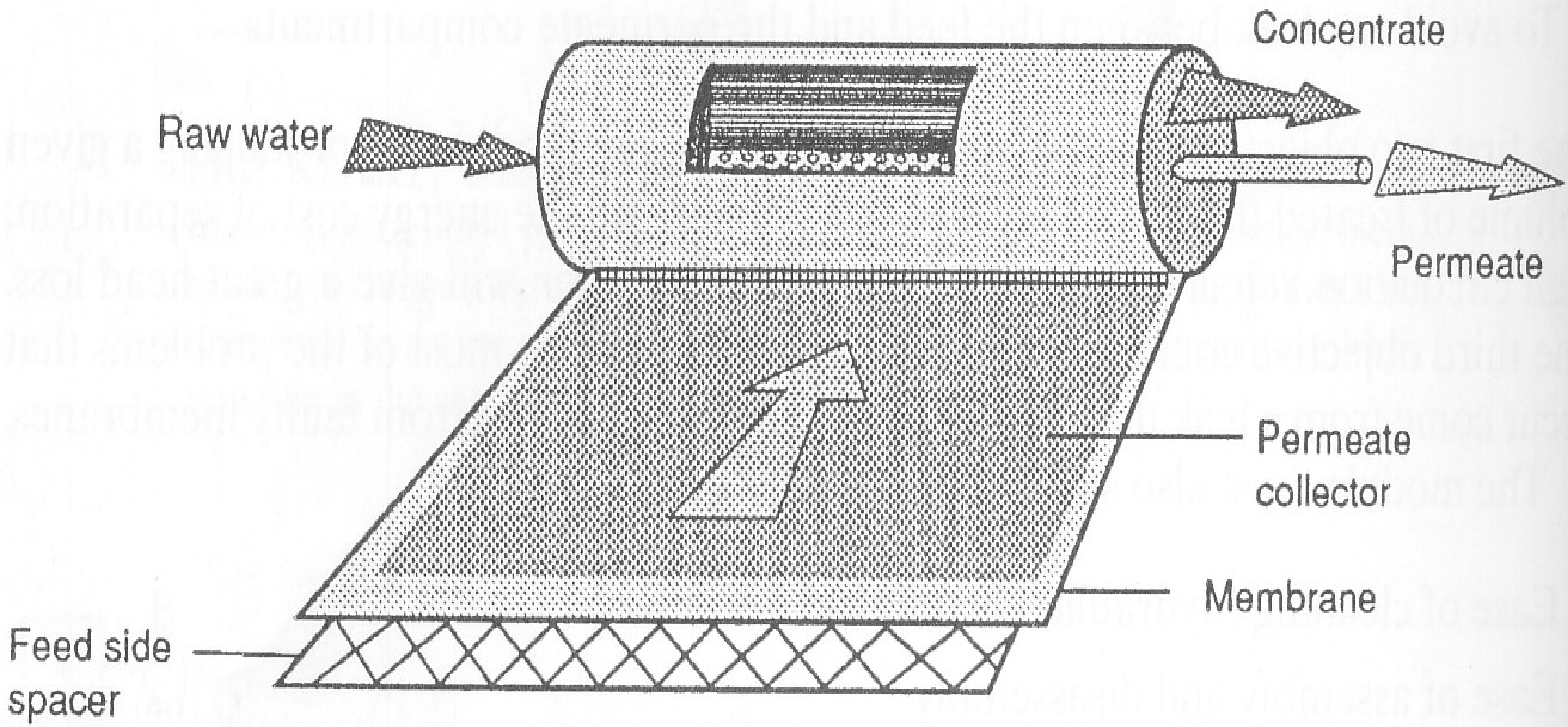
1 Cassette
8 ZeeWeed Modules



20' Frame
6 cassettes
48 modules

40' Frame
12
cassettes
96 modules

Membrane Configuration – Spiral Wound



(b)

Comparison of Membrane Configurations

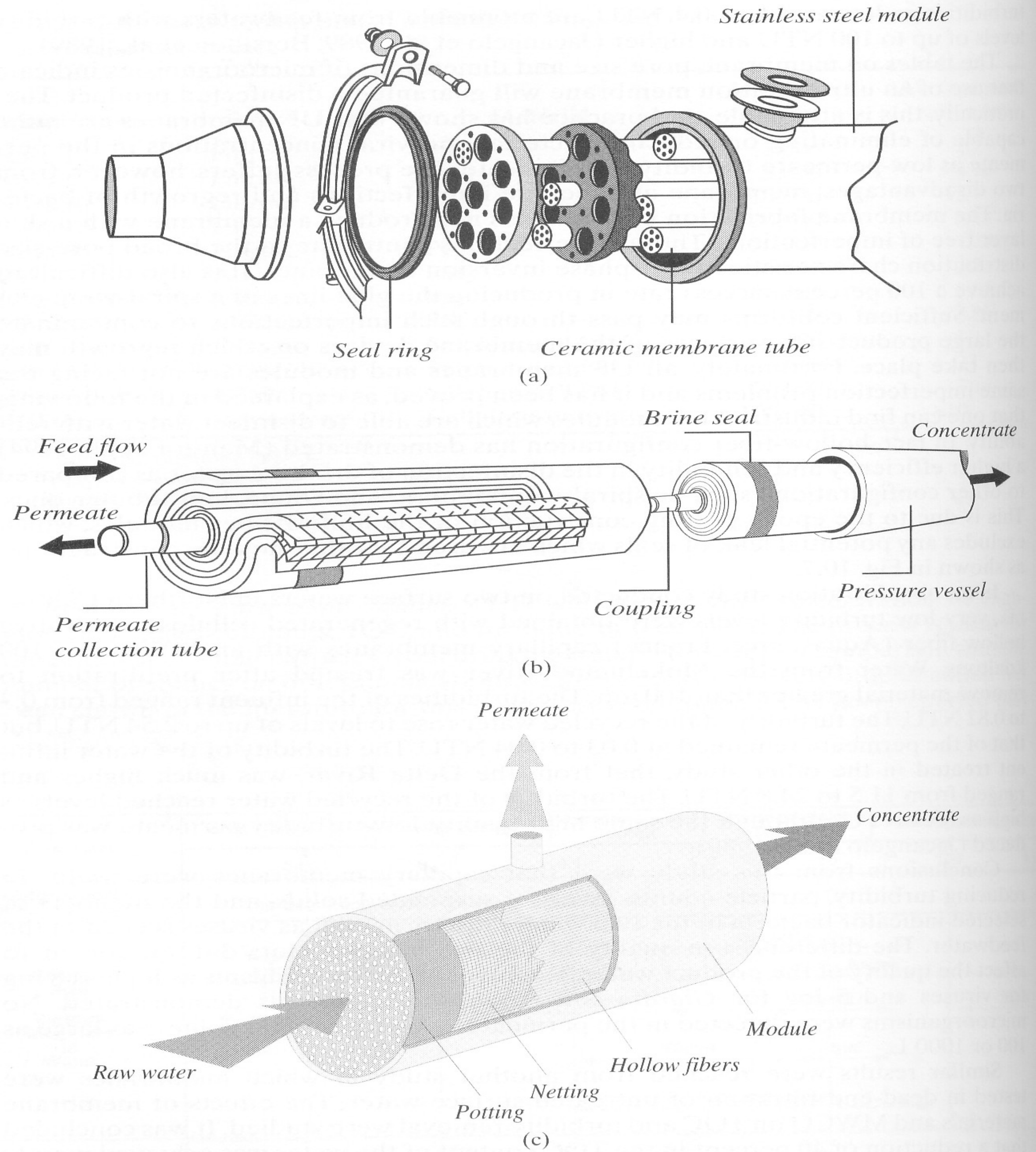


FIGURE 10.7 Comparison of construction characteristics for three types of modules: (*a*) connection of a tubular ceramic module; (*b*) assembly of the spiral-wound RO membrane elements; (*c*) hollow-fiber module—epoxy potting assembly.

Comparison of different types of modules

Criteria	Plate & frame	Spiral wound	Tubular	Hollow fibre
Packing density	+	++	-	+++
Ease of cleaning - in situ - by backflush	 + -	 - -	 ++ -	 - -
Cost of module	+	+++	-	+++
Pressure drop	-	++	+++	++
Hold-up volume	+	+	-	+++
Quality of pretreatment required	+	-	+++	-

Note: - clear disadvantages; +++ clear advantages

Part 2
Membrane Classifications

- According to separation mechanisms
- According to morphology
- According to geometry
- According to chemical nature

Membrane Classification

Separation Mechanisms – Major Classes

- Based on sieve effect
- Based on differences on solubility & diffusivity of membrane materials
- Based on differences in the charges of the species to be separated

Membrane classification

Separation Mechanisms – Sub Classes

- Porous membranes – MF, UF, NF, DIA
- Nonporous membranes – GP, PV, RO
- Ion exchange membranes – ED, NF

Membrane Classification

Morphology

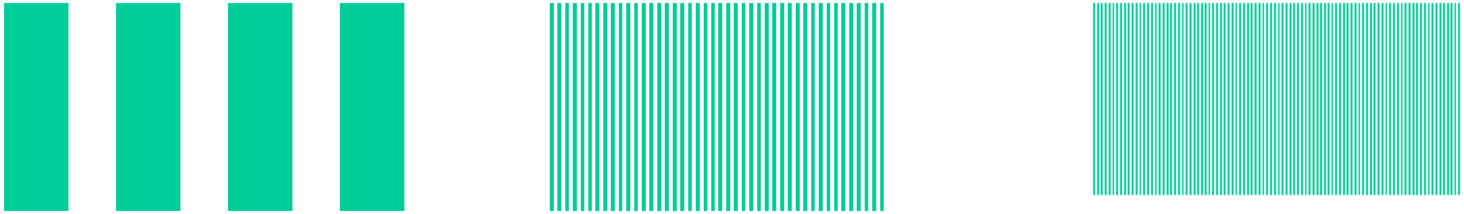
- Asymmetric membranes
- Composite membranes

Membrane Classification

Morphology

Membrane types	Size range
Macrophore (Microfiltration)	> 50 nm
Mesopores (Ultrafiltration)	2 > pore > 50 nm
Micropores (Nanofiltration, RO)	< 2 nm

Membrane Morphology

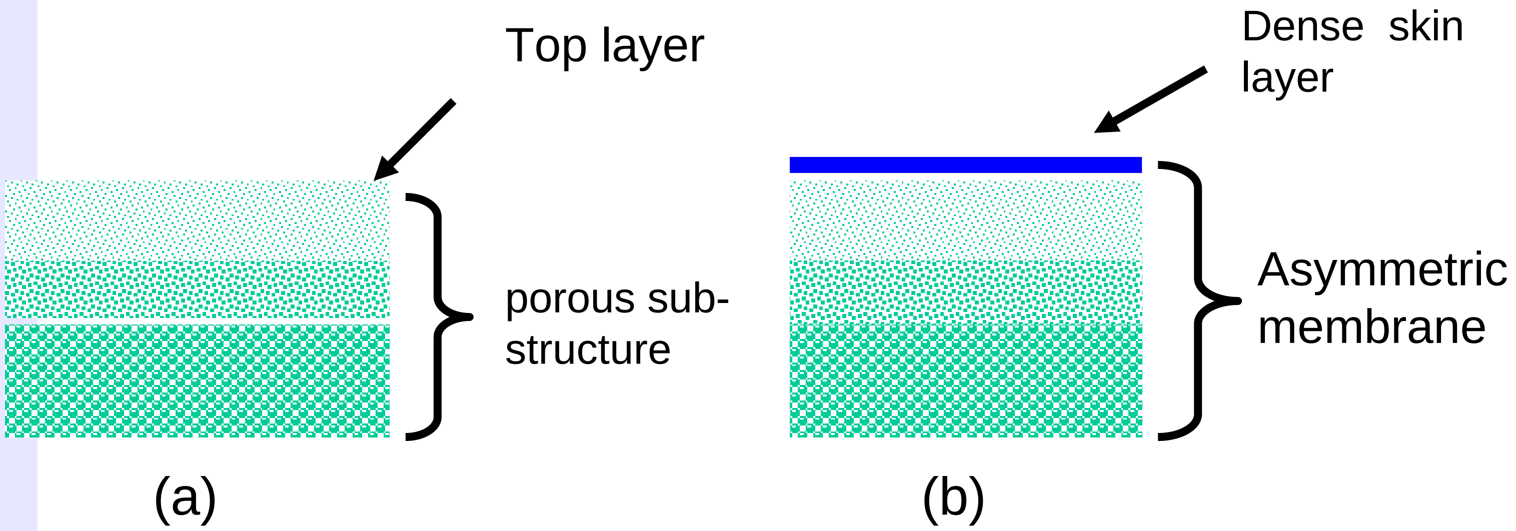


(a) (b) (c)

Side view schematic representation of isotropic porous membrane: (a) macropores > 50 nm; (b) 2< mesopores > 50 nm; (c) micropores < 2 nm.

Isotropic: **Denoting a medium whose physical properties are independent of direction. Opposite word**: ***Anisotropic***

Asymmetric & Composite Membranes



(a) Schematic drawing of an asymmetric membrane

(b) Schematic drawing of a composite membrane

Membranes Operations

Driving Force	Process	Mechanism	Membrane
Pressure	MF	Sieving (0.1-10 μm)	Open porous
Pressure	UF	Sieving (1-100 nm)	Skinned-porous
Pressure	NF	Solution diffusion	Dense skinned
Pressure	RO	Solution diffusion	Dense skinned

Membrane Materials

- Ceramics
- Glass
- Metals
- Polymers

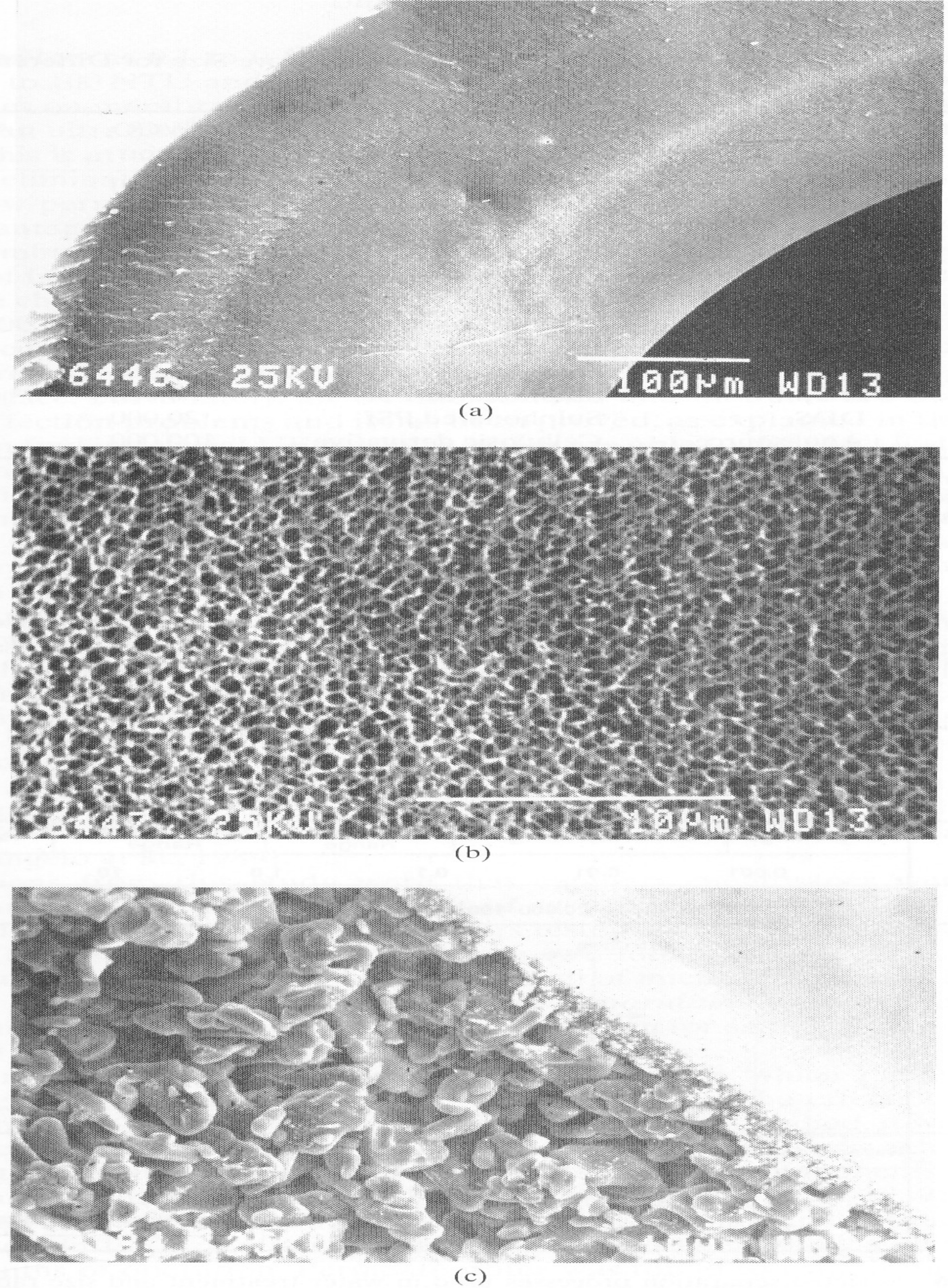


FIGURE 10.5 Modular structure of a UF polymeric: (*a*) and (*b*) Aquasource; and a ceramic membrane (*c*) Techsep.

Important Material Properties

- Thermal stability
- Crystallinity
- Chemical resistance
  - ✓ Process fluid / gas
  - ✓ Chemical cleaning reagents
    - oxidative
    - hydrolysis
    - detergents (neutral, ionic)
- High permeability
- High selectivity
- Stable operation

Important Materials (MF, UF, NF, RO)

Generic materials	Specific
Cellulose	✓ cellulose ✓ cellulose diacetate ✓ cellulose triacetate
Polysulphones	✓ poly(ether sulphone) ✓ polysulphone
Polyolefins	✓ polyethylene ✓ polypropylene

Commercial Polymer Membrane Materials

• Polypropylene (PP)	MF
• Polytetrafluorthylene (PTFE)	MF
• Polyvinylidenefluoride (PVDF)	MF, UF
• Aliphatic polyamide (Nylon 6,6,6)	MF, UF
• Polysulphone (PSf)	MF, UF
• Polyethersulphone (PES)	MF, UF
• Polytherimide (PEI)	MF, UF
• Polyethertherketone (PEEK)	MF, UF
• Polyacrylonitrile (PAN)	UF
• Aromatic polyamide	MF, UF, RO
• Polyimide (PI)	MF, UF, RO
• Cellulose acetate (CA)	MF, UF, RO
• Cellulose triacetate (CTA)	RO

Part 3
Pressure-Driven Membrane Types

- Microfiltration
- Ultrafiltration
- Nanofiltration
- Reverse osmosis

Part 4:

Pressure-Driven Membrane Systems

- Conventional modular package (side stream)
- Immersed (submerged) package

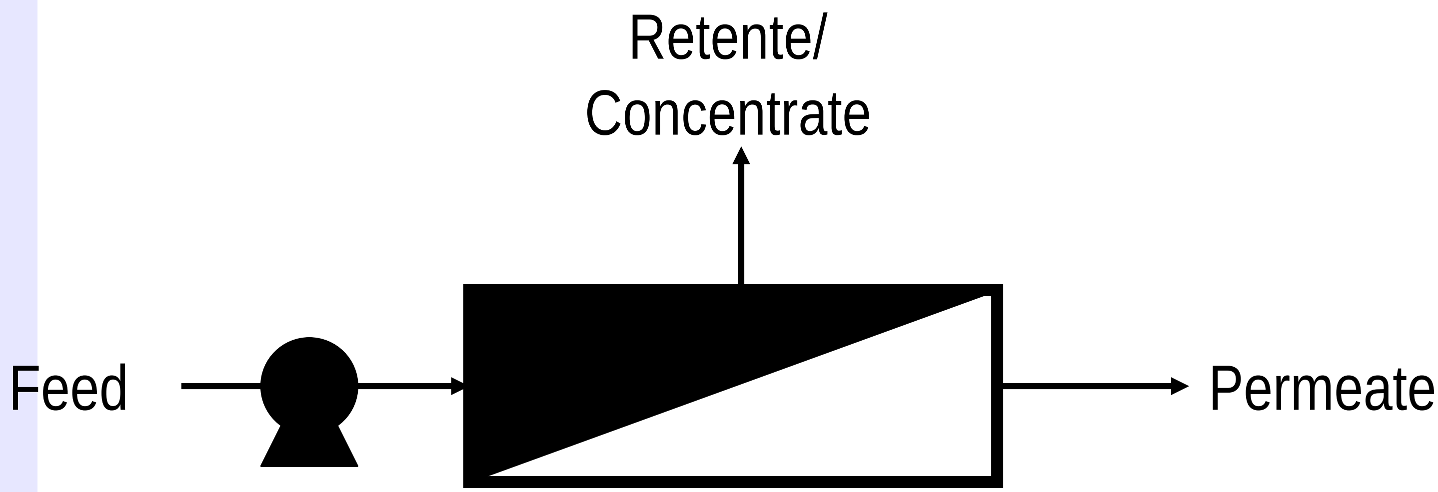
Conventional Modular Package

- Conventional type
- Feed is to be pressurised to the module under <u>outside-in</u> arrangement
- <u>High pressure</u> is required to maintain permeate flow
- Fouling is the main operational problem
- Life span membrane is at stake

Why Immersed System?

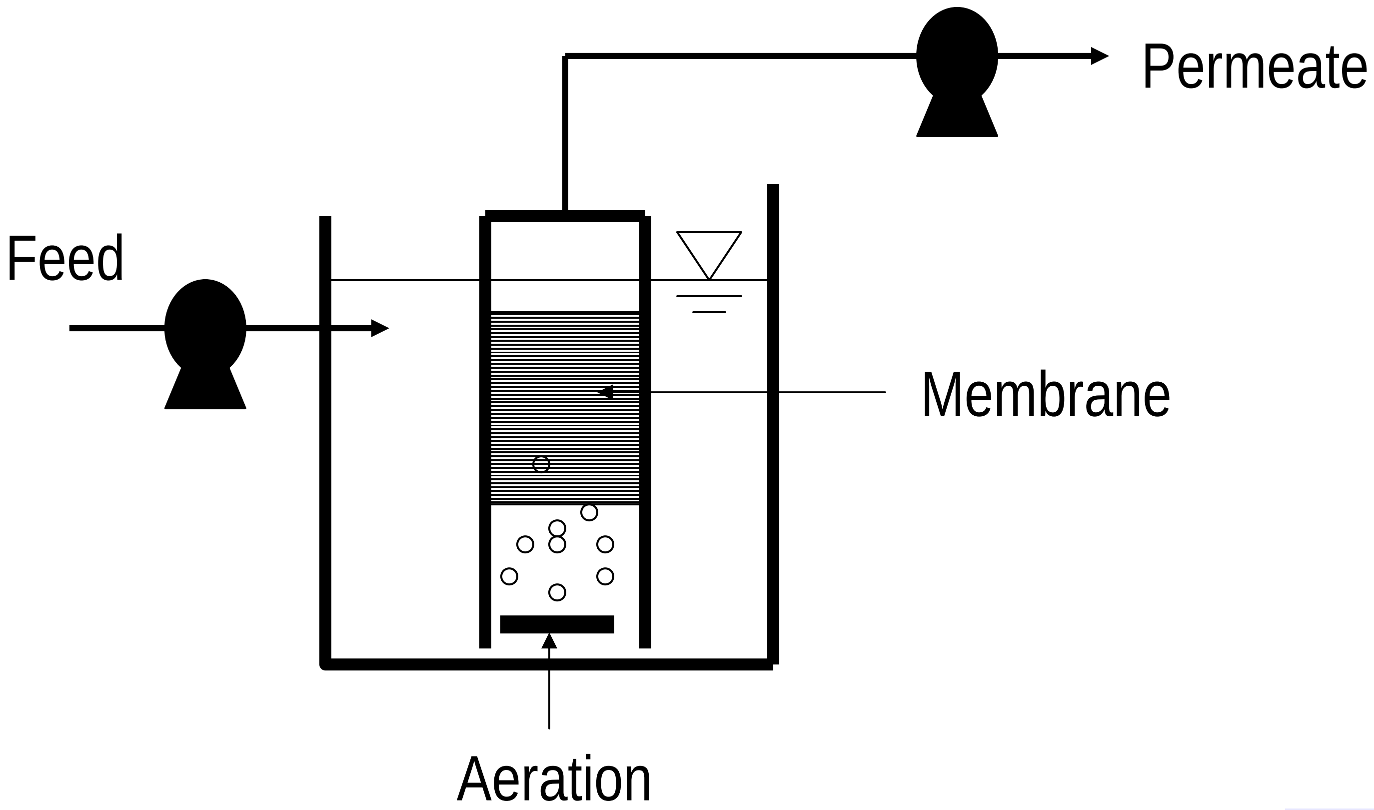
- Low pressure system
- Hybrid with biochemical processes
- Hybrid with chemical processes
- Less fouling problems
- Relatively easier cleaning procedure
- Less sludge or by-products production

Conventional membrane package

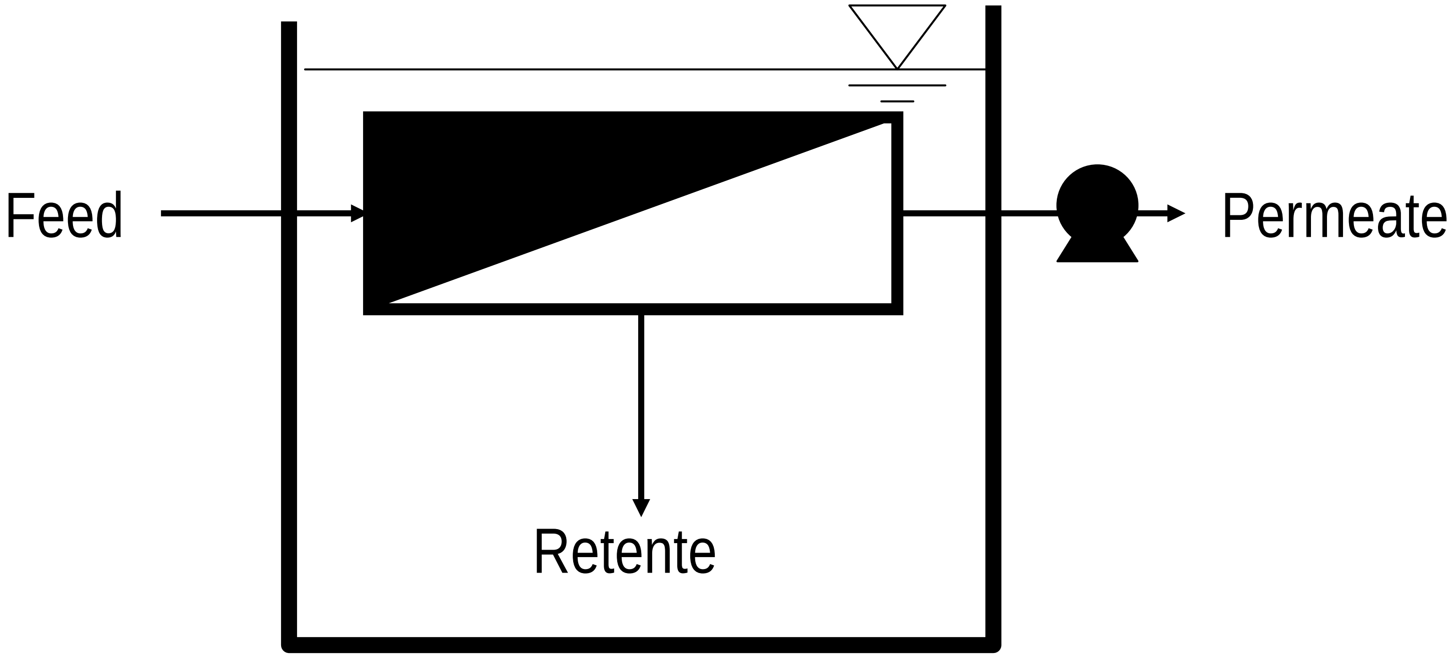


Membrane plant for water treatment, Ogose Town, Japan

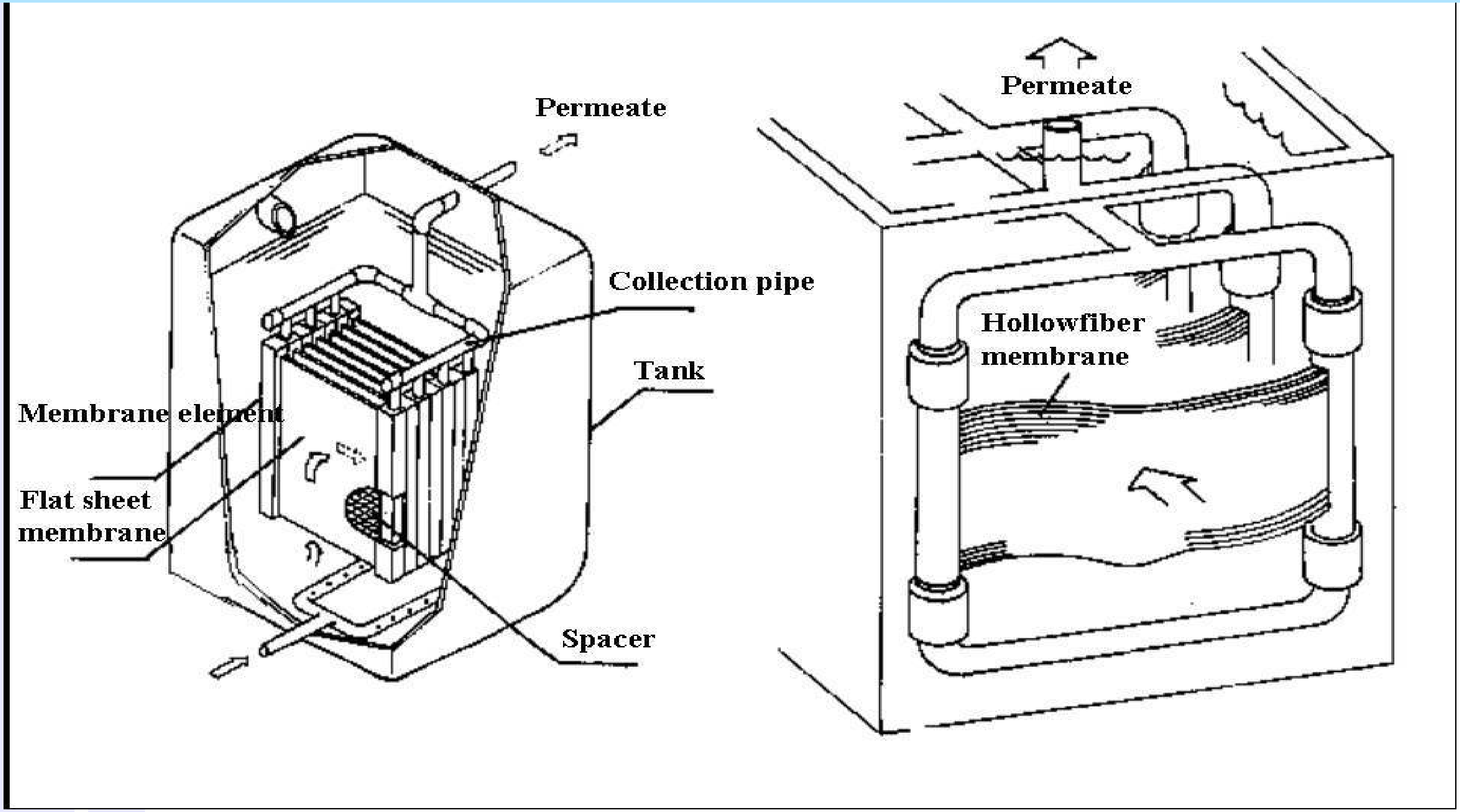
Immersed membrane package



Immersed membrane

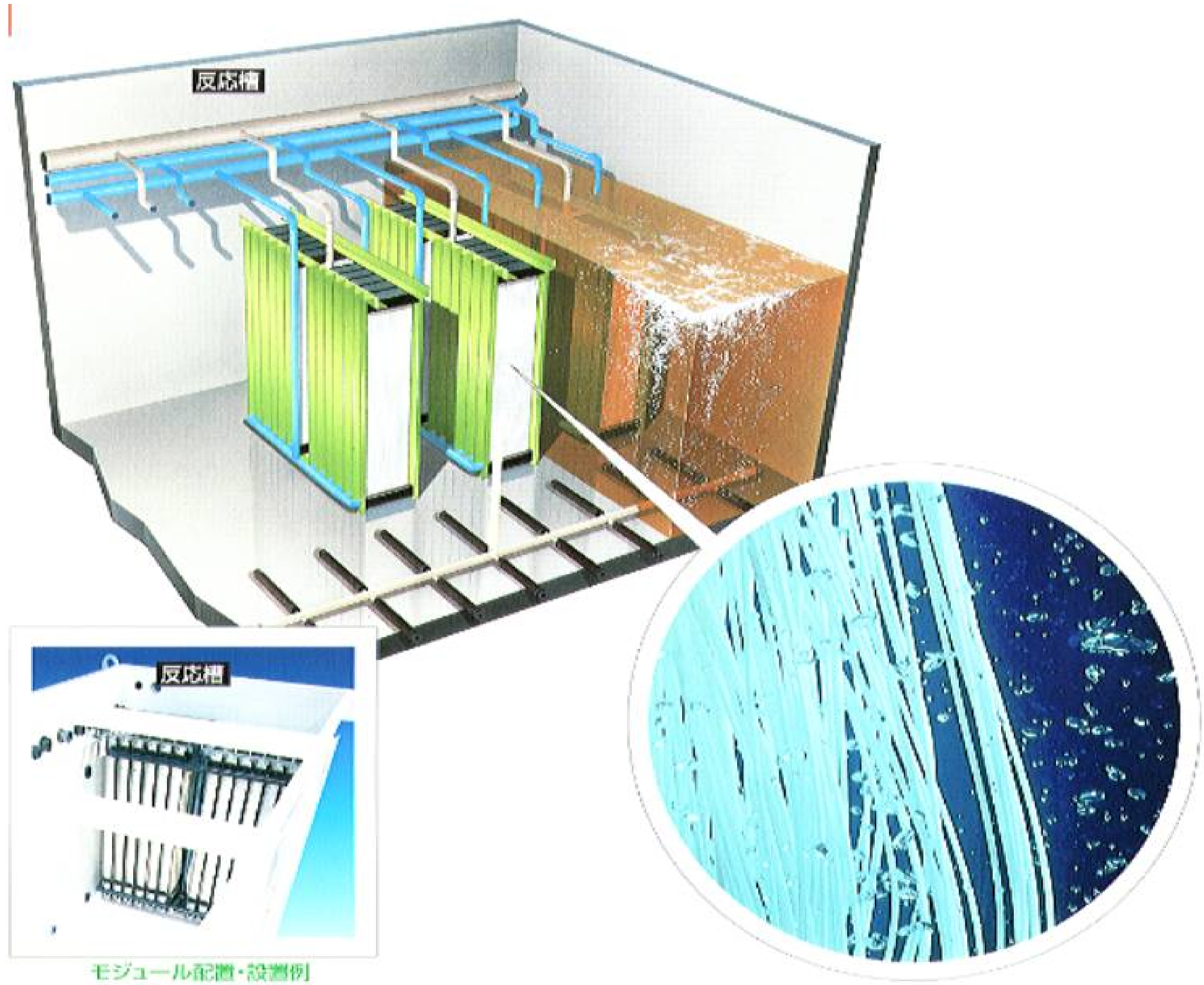


Immersed Membrane

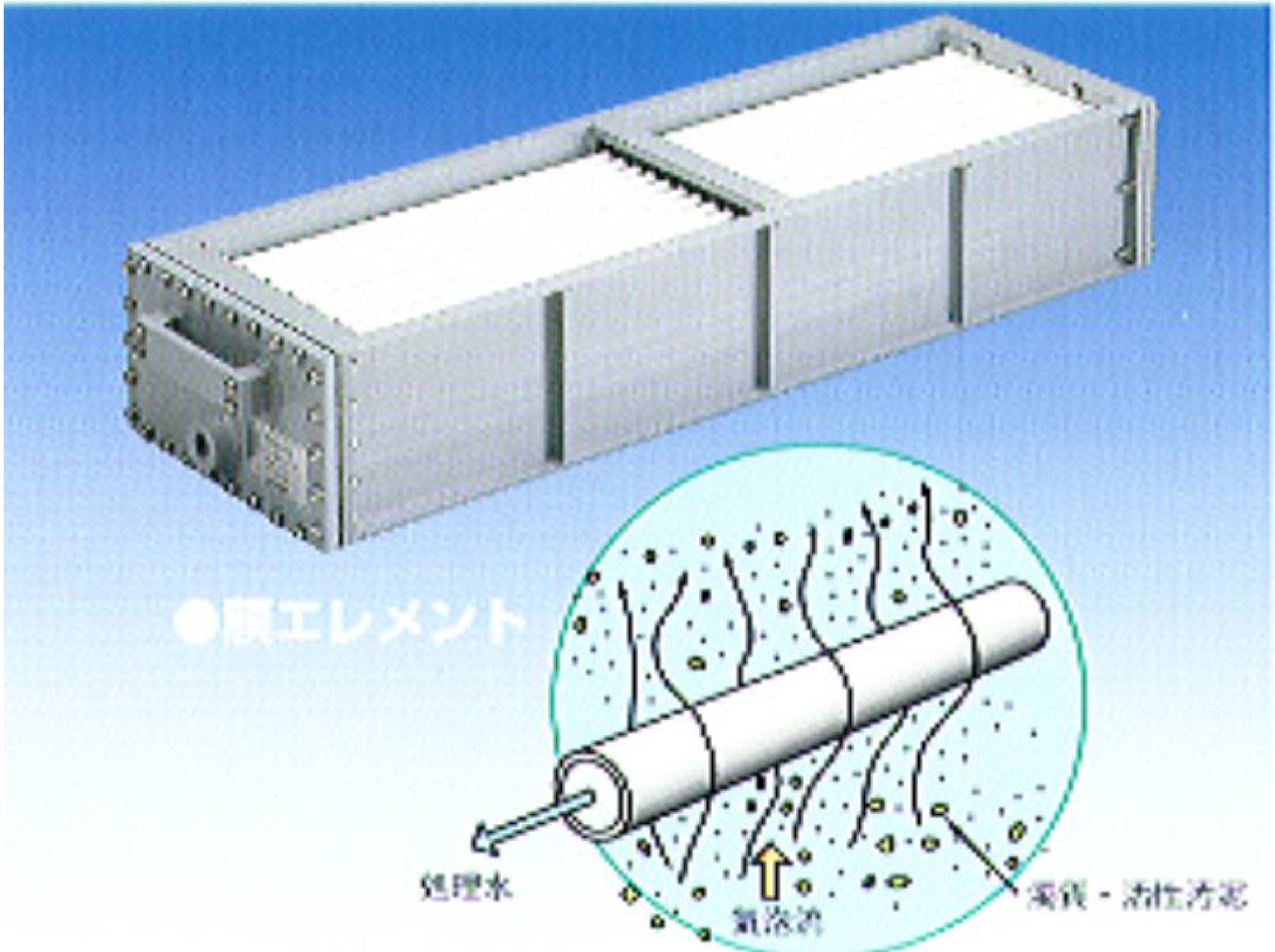


(a) Flat Sheet Membrane (b) Hollow Fibre Membrane

Zenon’s MF Hollow-Fibre Module



Kubota's MF Tubular (Ceramic)



Membrane Bioreactor (MBR)

Membrane Bioreactor

- Low pressure system
- Hybrid with biochemical processes
- Less fouling problems
- Relatively easier cleaning procedure
- Less sludge or by-products production

2000. MBR Pilot Plants in Tokyo (a) Mitsubishi (b) Kubota

MBR by Mitsubishi Rayon Engineering

Mitsubishi Rayon Engineering MBR, Tokyo

Items	Pilot Plant Conditions
Treatment Capacity (m^3/d)	32-48
Type of filtration	Continuous flow
Flux ($m^3/m^2.d$)	Operating flux 0.5-0.7 Daily average 0.4-0.6
Intermittent operation (min)	Operating: 8-12; Stop: 2
MLSS (g/l)	10
Air diffusion ($m^3/m^2.s$)	0.06
Retention time (h)	5.5 - 8.0
Recirculation ratio	3

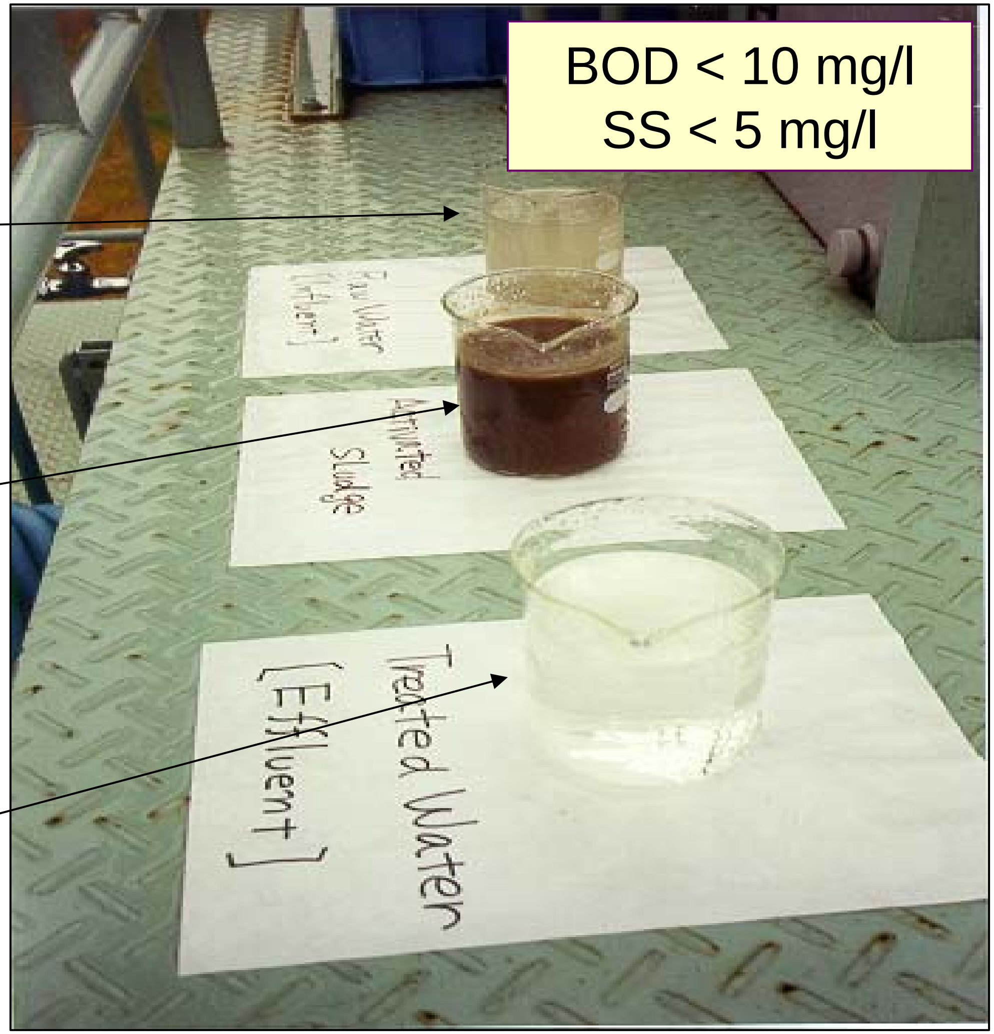
Effluent of MBR from Mitsubishi Pilot Plant

BOD < 10 mg/l
SS < 5 mg/l

Feed

Activated sludge

Treated effluent



Financial Comparison
MBR with Conventional Activated Sludge

Items	MBR	CAS
Sludge (m^3/day)	0.069	0.963
Operating cost* ($/day)	8.37	11.25
Sludge treatment* ($/day)	34.65	48.3
Running cost	72%	100%
Space	30%	100%

* Price for electricity at US$0.075

Source: MRC, 1997 (in Visvanathan *et al.*, 2000)

Part 5: Wastewater treatment plant design advisor (WASDA)

Decision Support System

- Interactive computer-based tools used by decision makers since 1960s to help answer questions, solve problems and support or refute conclusions
- Concepts: Spreadsheets, databases, networks, hypermedia, expert systems, visual programming, intelligent agents, neural networks, etc.
- Potential to improve decision quality, competitive edge, time-saving and productivity when users have both sufficient technical knowledge of the system and enough experience of the job.
- Widely used for the solution of various engineering and management problems

WASDA in perspective

- Wastewater Treatment Plant Design Advisor.
- Decision Support System (DSS) – developed by UTM
- Artificial Intelligence (AI) applications
- Wastewater treatment plant design approach.
- Contains 2 main parts:
  - (a) Knowledge / information base
  - (b) Design calculation spreadsheet

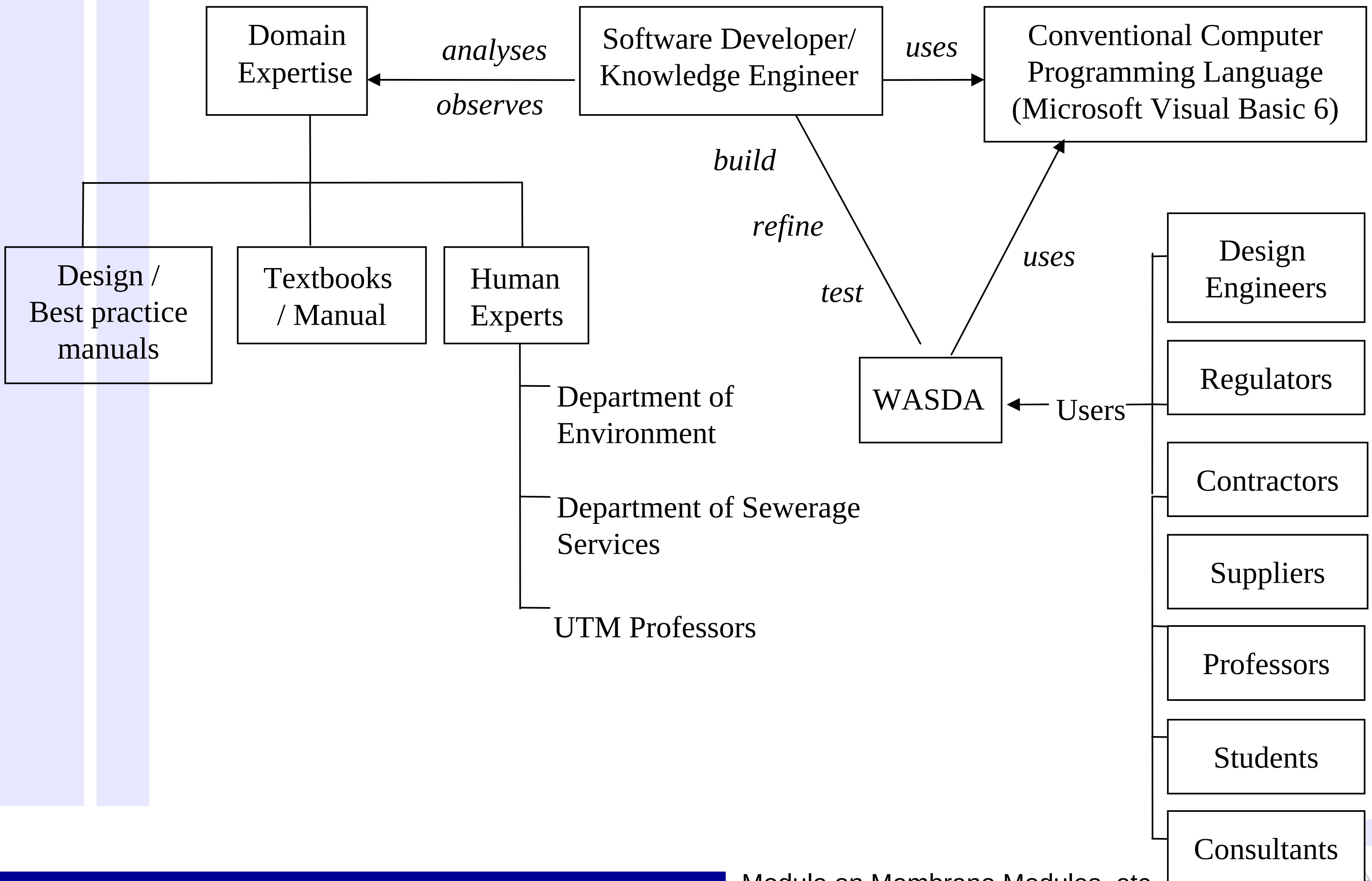
WASDA in perspective

- Information base in WASDA represented as “if-then” rules & “frames / forms and objects”.
- Provides conceptual & process design recommendations for conventional wastewater, primary, secondary & advanced treatments – proposed by best practical manuals / public authorities (sewerage services / environmental control).
- WASDA mainly focused on municipal and industrial applications to produce conceptual and process design for primary, secondary and advanced treatments.

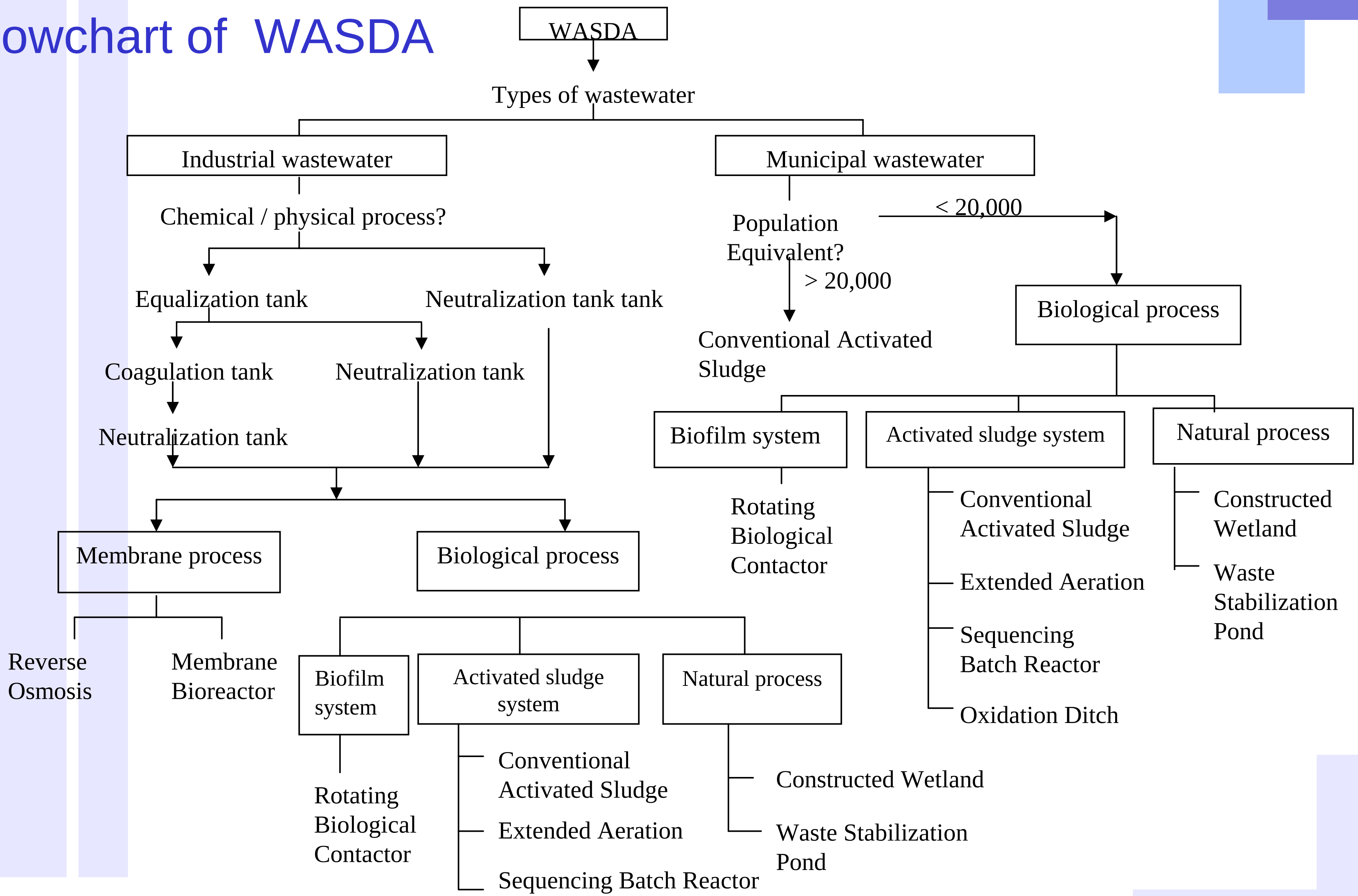
Modules in WASDA

- Equalization tanks
- Conventional activated sludge
- Extended aeration
- Oxidation ditch
- Sequencing batch reactor
- Rotating biological contactors
- Constructed wetlands – surface flow
- Constructed wetlands – subsurface flow
- Membrane technology

WASDA architecture



Flowchart of WASDA



Architecture of Membrane-RO Module

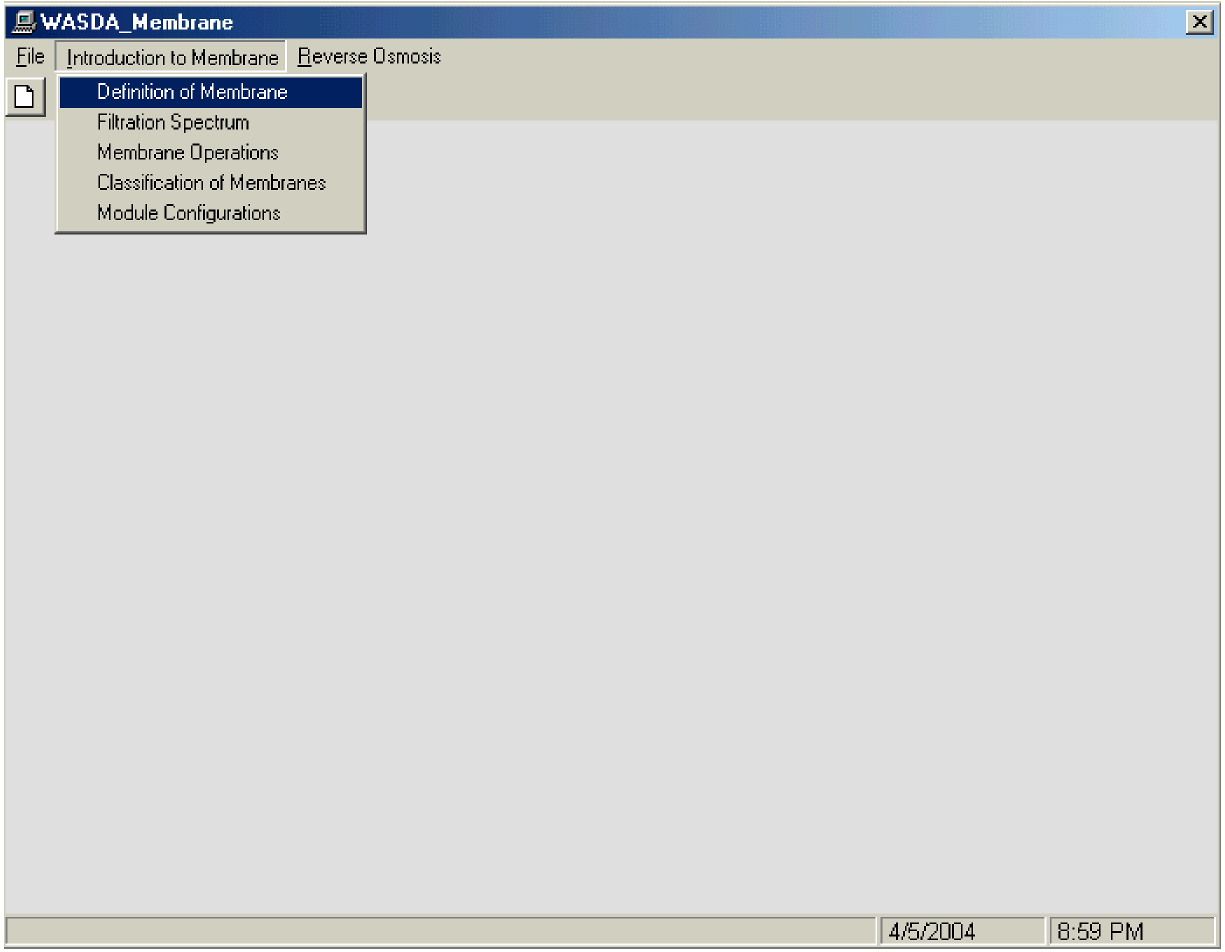
Design advisor or knowledge base forms:

- Design considerations and parameters
- Process stages and flow chart
- Process description
- General calculation design - SDI.

Computerized design spreadsheet

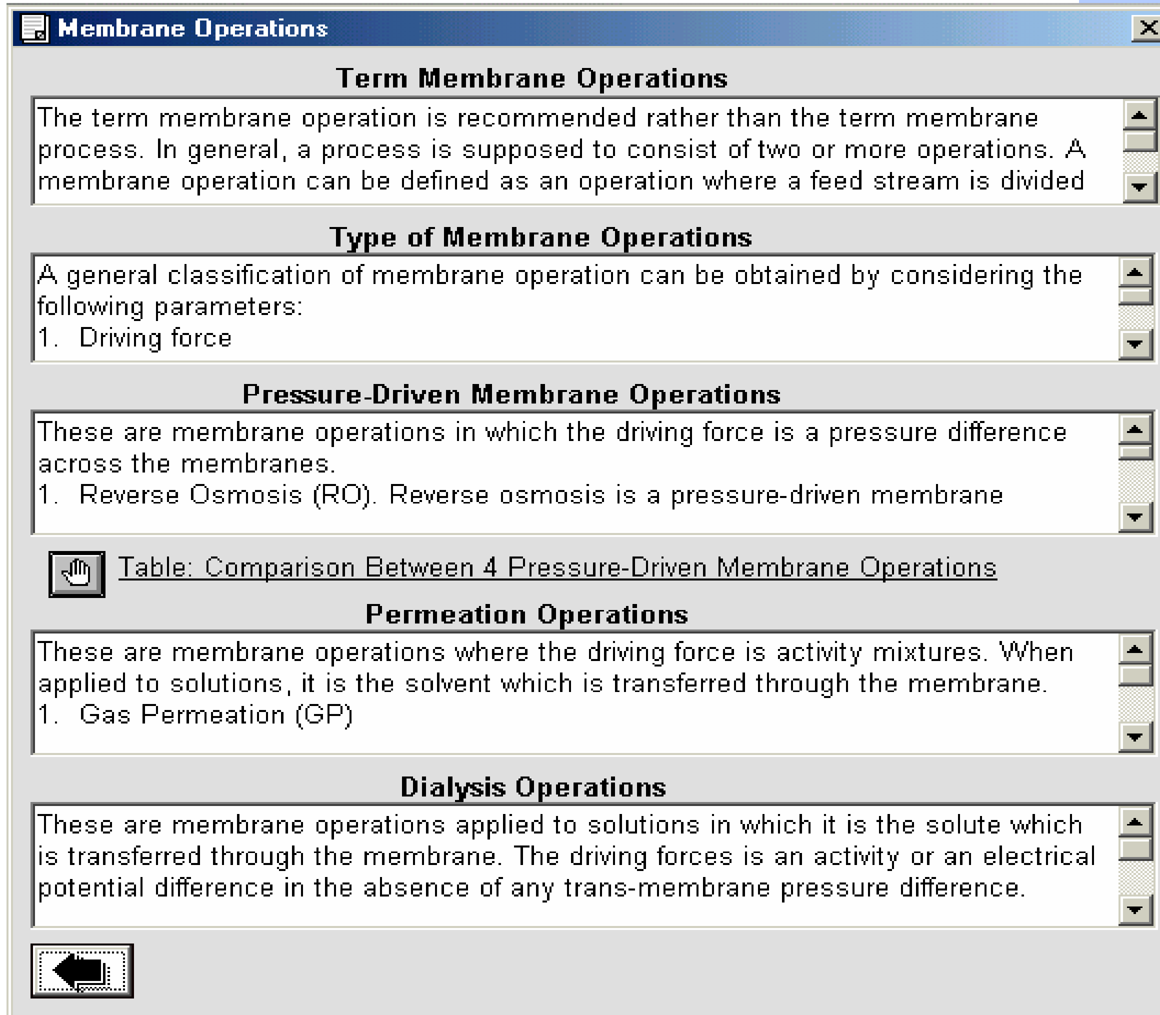
Forms in Membrane-RO Module

Main form of Membrane module →



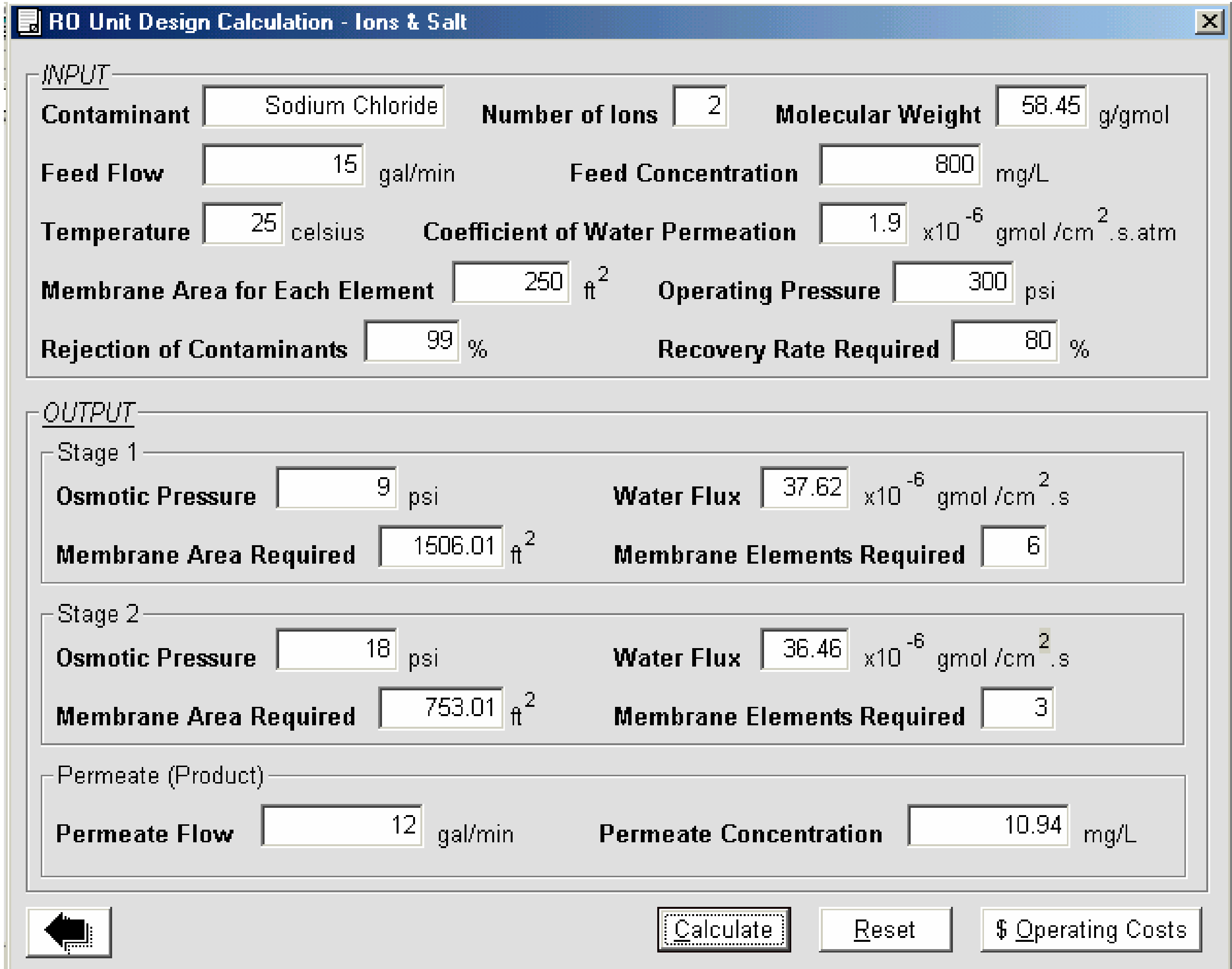
Forms in Membrane-RO Module

Membrane operations form



Forms in Membrane-RO Module

RO Unit Design Calculation form →


RO Unit Design Calculation - Ions & Salt

INPUT

Contaminant: Sodium Chloride | Number of Ions: 2 | Molecular Weight: 58.45 g/gmol

Feed Flow: 15 gal/min | Feed Concentration: 800 mg/L

Temperature: 25 celsius | Coefficient of Water Permeation: 1.9 $x10^{-6}$ gmol /cm^2.s.atm

Membrane Area for Each Element: 250 ft^2 | Operating Pressure: 300 psi

Rejection of Contaminants: 99 % | Recovery Rate Required: 80 %

OUTPUT

Stage 1

Osmotic Pressure: 9 psi | Water Flux: 37.62 $x10^{-6}$ gmol /cm^2.s

Membrane Area Required: 1506.01 ft^2 | Membrane Elements Required: 6

Stage 2

Osmotic Pressure: 18 psi | Water Flux: 36.46 $x10^{-6}$ gmol /cm^2.s

Membrane Area Required: 753.01 ft^2 | Membrane Elements Required: 3

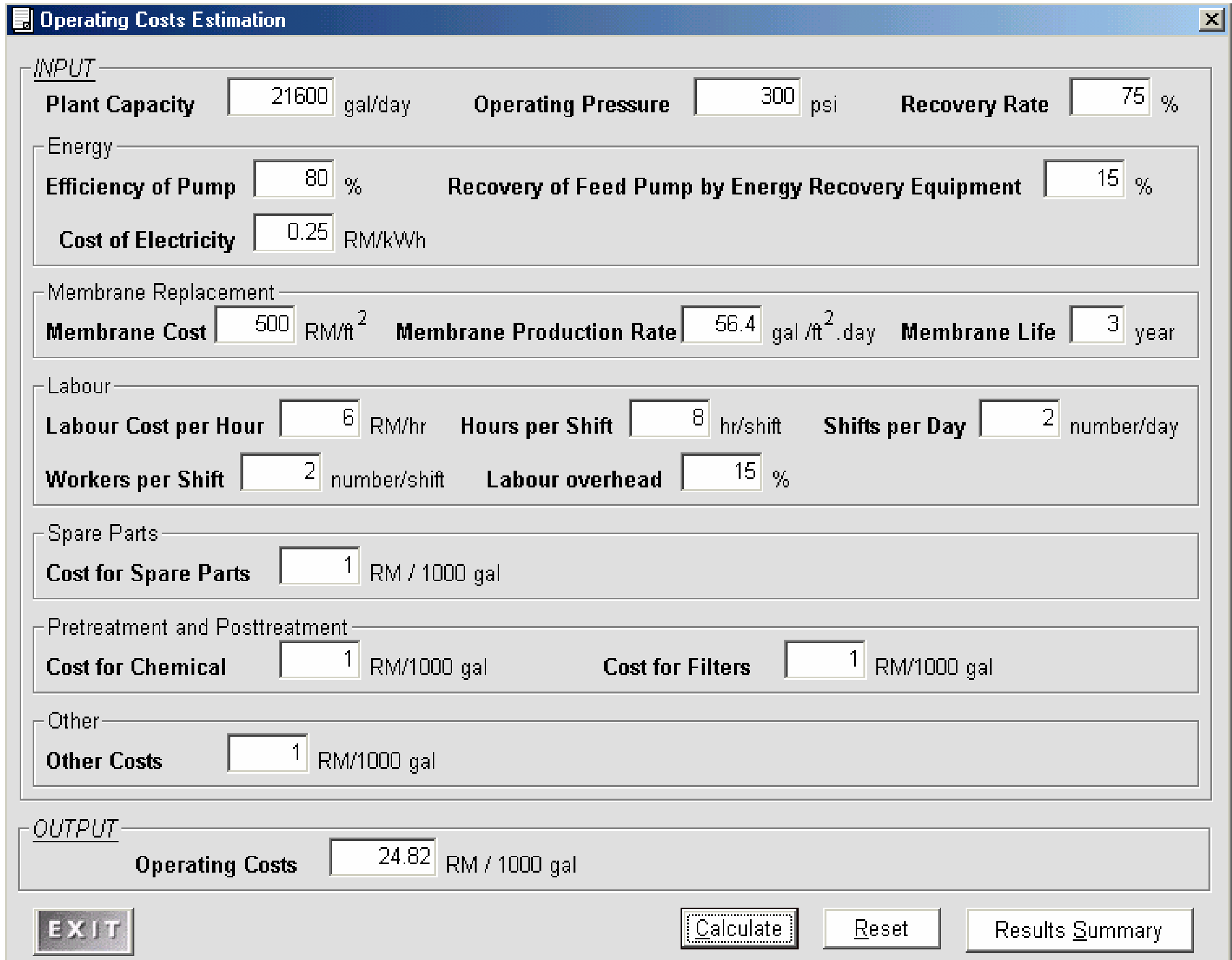
Permeate (Product)

Permeate Flow: 12 gal/min | Permeate Concentration: 10.94 mg/L

Calculate | Reset | $ Operating Costs

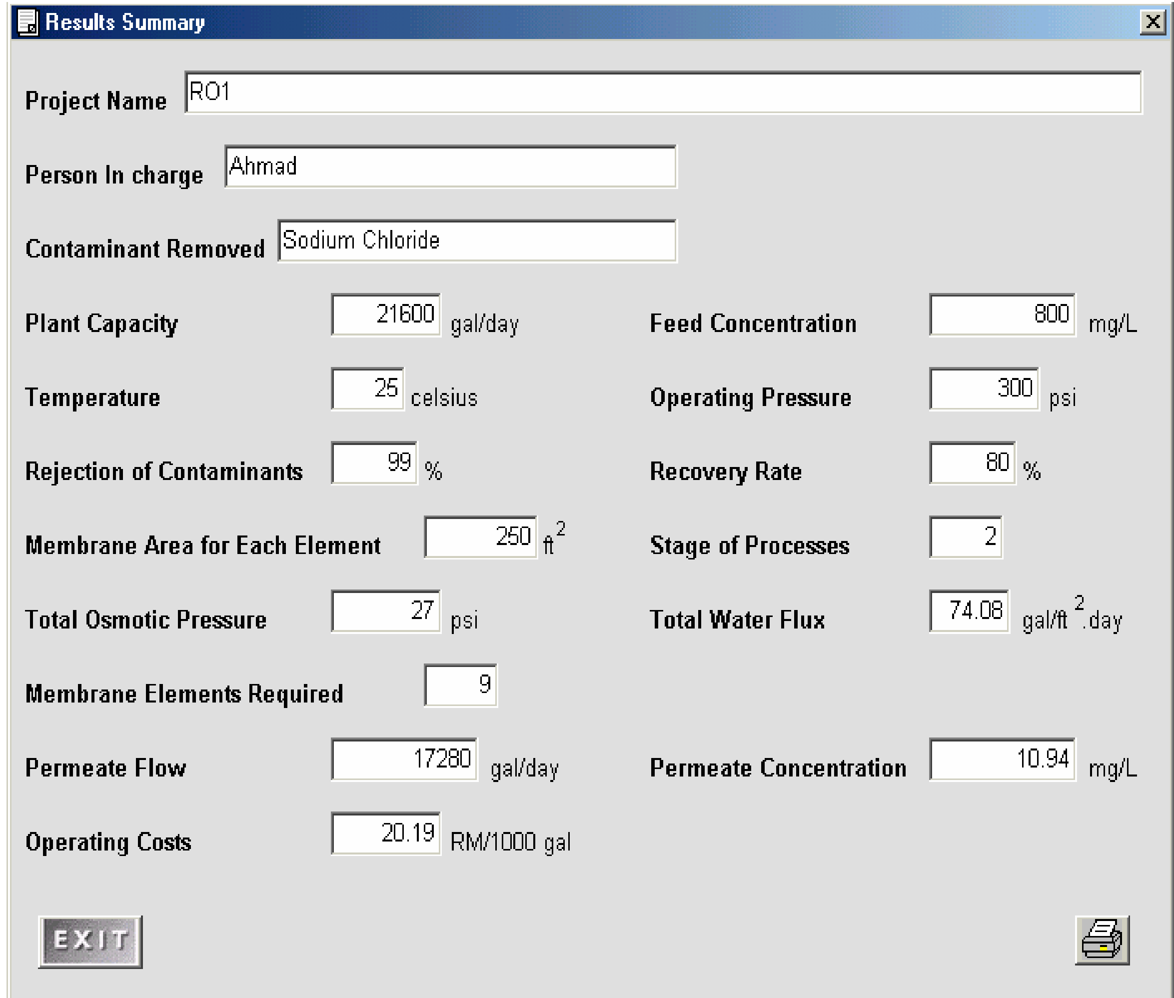
Forms in Membrane-RO Module

Operating cost estimation form →



Forms in Membrane-RO Module

Result summary form →



Conclusion

- WASDA decision support system for membrane module is an efficient tool to provide uniform information on Membrane process design as verified by program debugging, error analysis, data input and output analysis.
- It can assist users to consider the membrane system as one of the good alternatives to treat water and wastewater
- Users can optimize resources and time.