UTM
UNIVERSITI TEKNOLOGI MALAYSIA

INSPIRING CREATIVE AND INNOVATIVE MINDS

www.utm.my

Specialized Short Course on MEMBRANE TECHNOLOGY for Water and Wastewater Treatment

27 – 28 June 2009 (4 -5 Rajab 1430 H)

Prince Khalid bin Sultan Chair for Water Research
Civil Engineering Department, Hall 1 A 36
College of Engineering, King Saud University

Lecture 3
Back to Basic 2: Membrane Module Configurations, Classification, Types and Systems

Prof. Dr. Ir. Zaini Ujang
Ph.D, P.Eng. (M), C.Eng. (UK), C.Sci. (UK), C.W.E.M. (UK), MIEM, DNS, PPI

Institute of Environmental and Water Resources Management (IPASA)
Universiti Teknologi Malaysia

Presentation Menu

Part 1: Module configurations

Part 2: Membrane classification

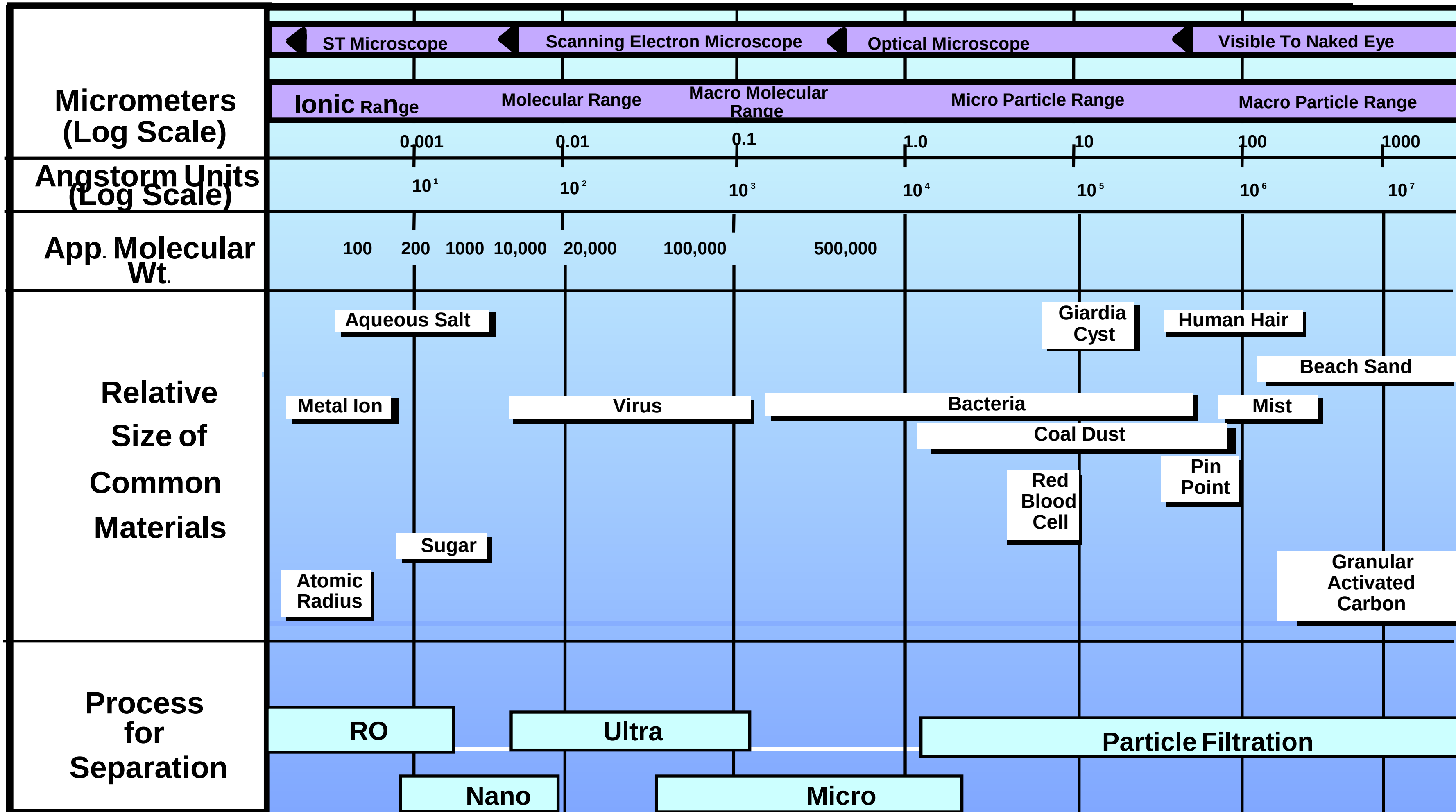
Part 3: Membrane types

Part 4: Membrane systems

Part 5: Membrane design using WASDA

Spiral Wound Configuration

Filtration Spectrum



Part 1. Module Configuration

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

Objectives of Module Configuration

- 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 Configuration – Flat Sheet

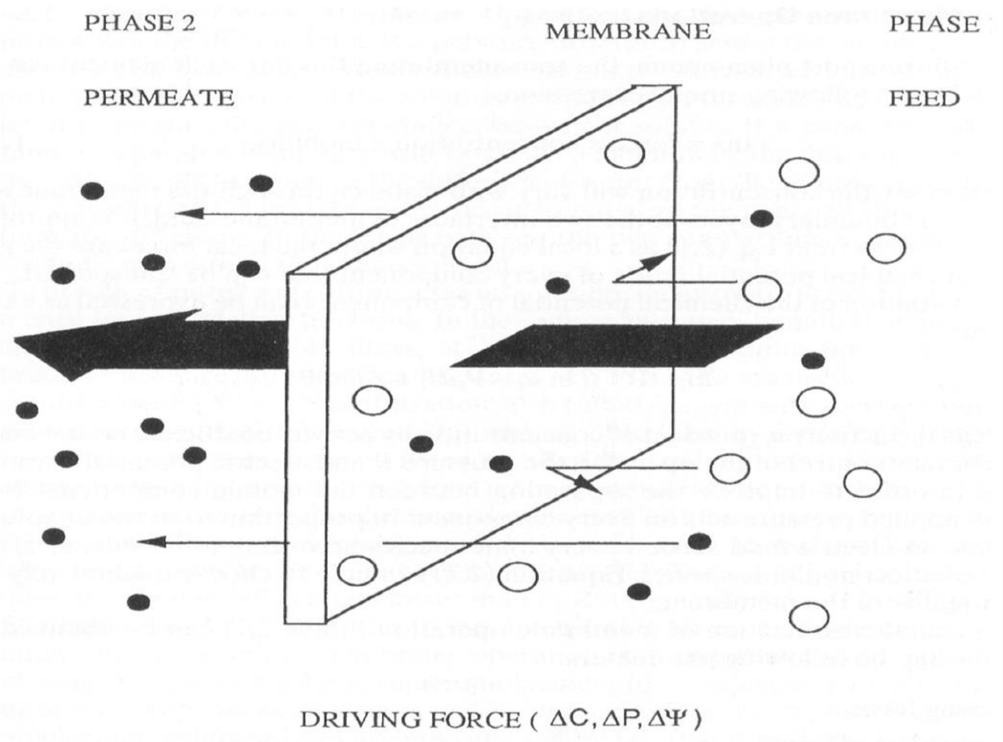
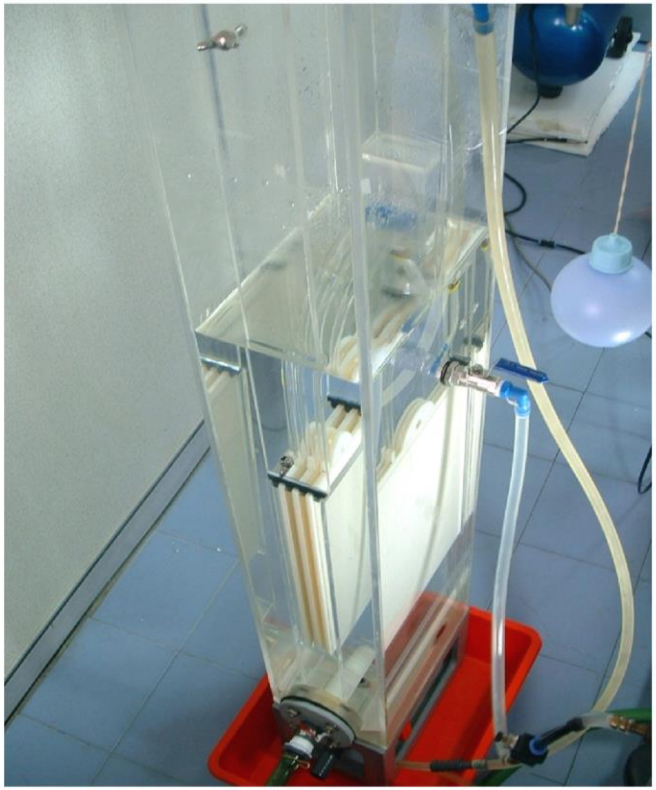


FIGURE 2.1 Definition of a permselective membrane.



Module Configuration - Tubular

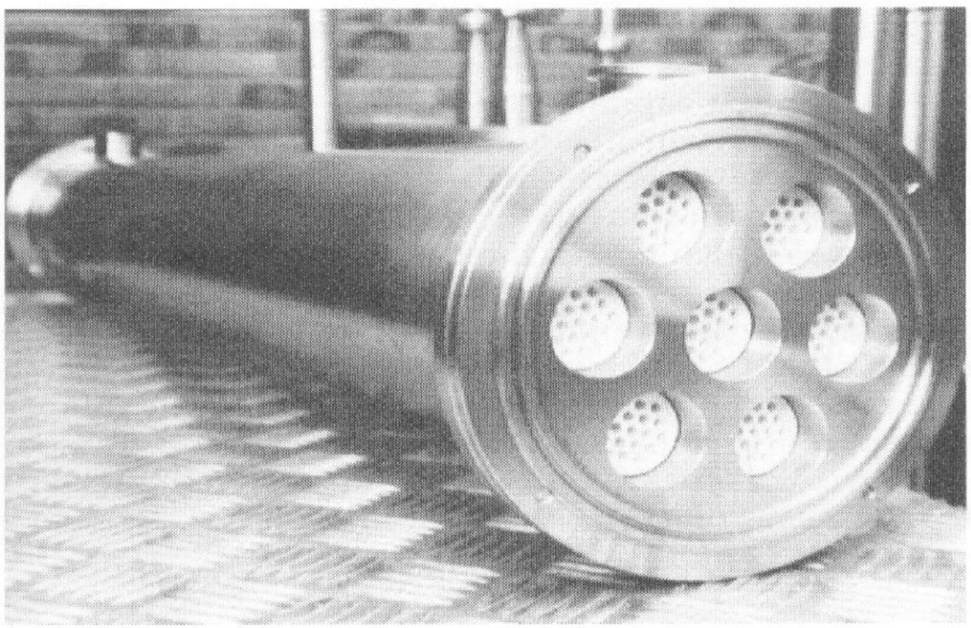
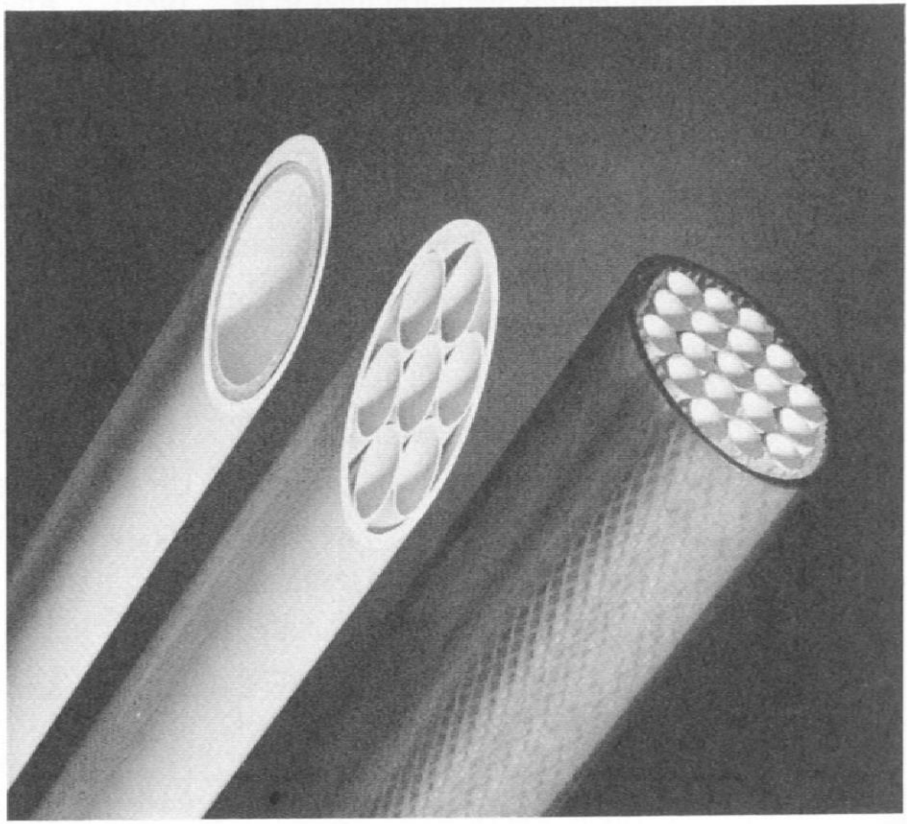


FIGURE 10.10 Example of a tubular ceramic membrane module. *(Kerasep-Techsep.)*

Module Configuration - 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.)



UTM UNIVERSITI TEKNOLOGI MALAYSIA

www.utm.my

Module Configuration – Hollow Fibre

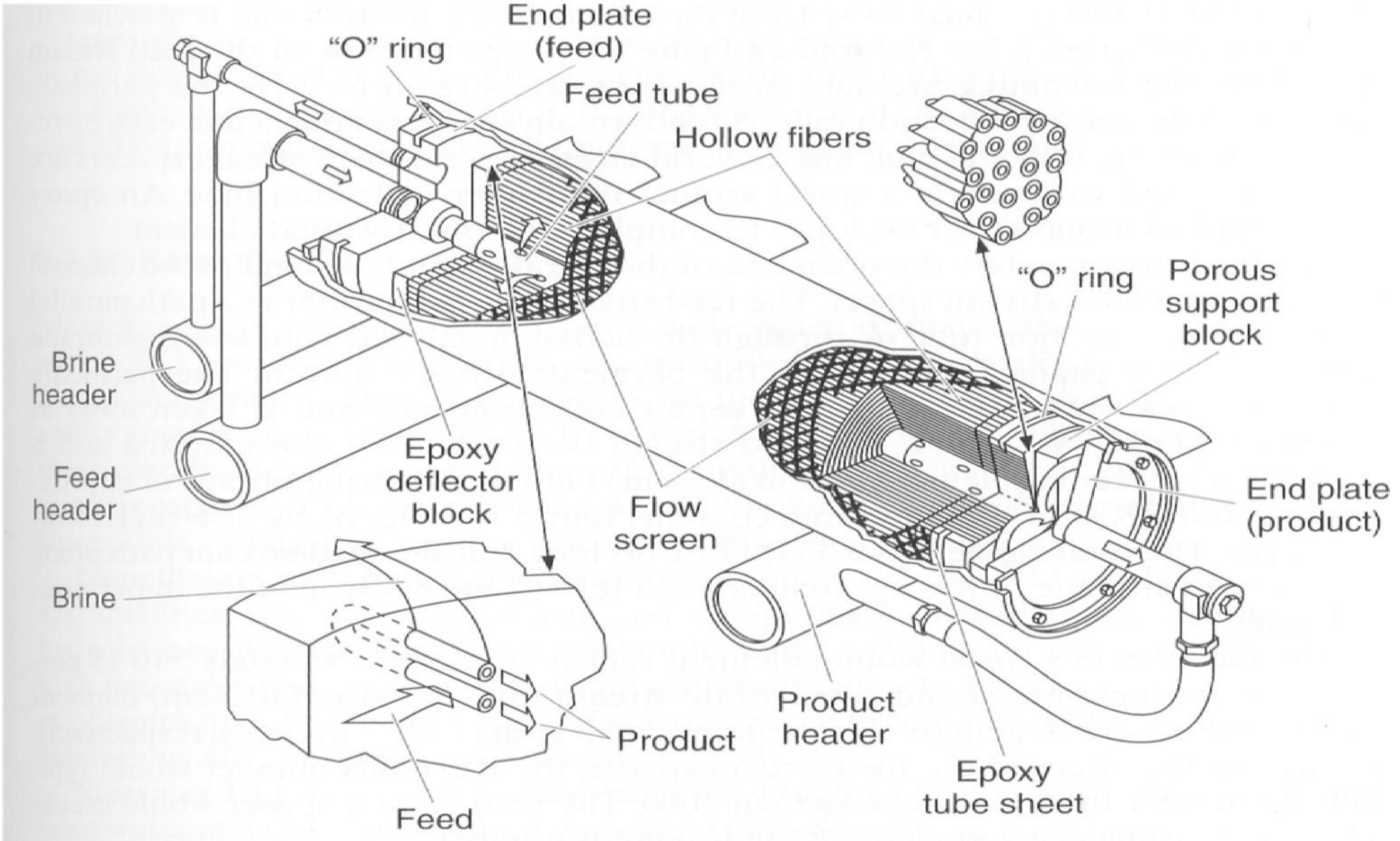
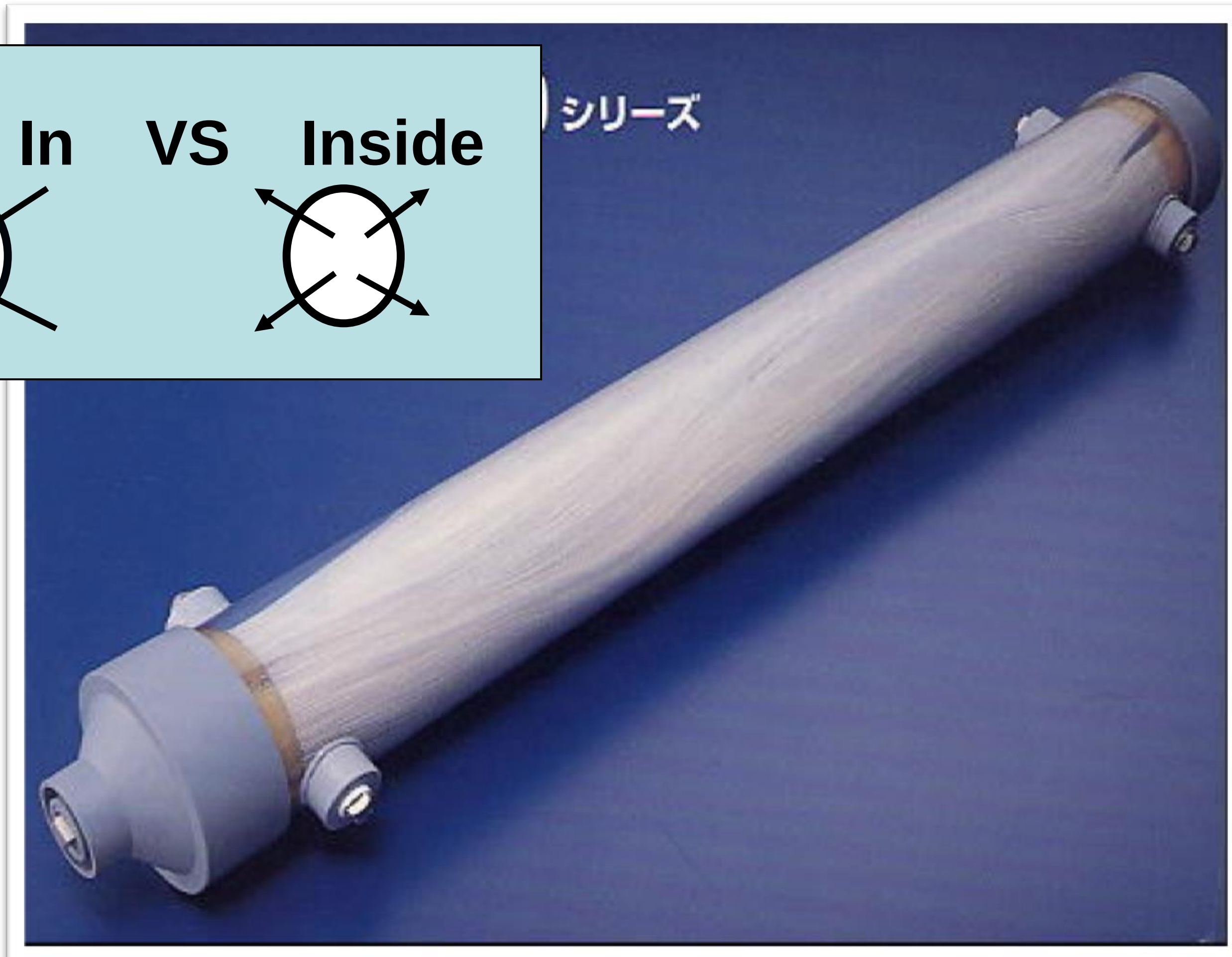


FIGURE 9.1 Diagram of a hollow fine-fiber reverse-osmosis membrane element.

Module Configuration – Hollow Fibre

Outside In VS Inside Out

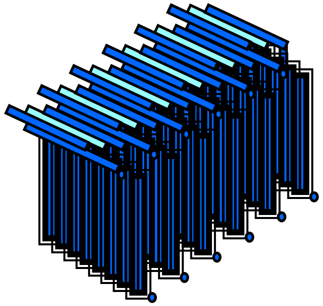


UTM
UNIVERSITI TEKNOLOGI MALAYSIA
www.utm.my

Module Configuration –
Hollow Fiber (ZeeWeed® Modules)

60 m^2 per module

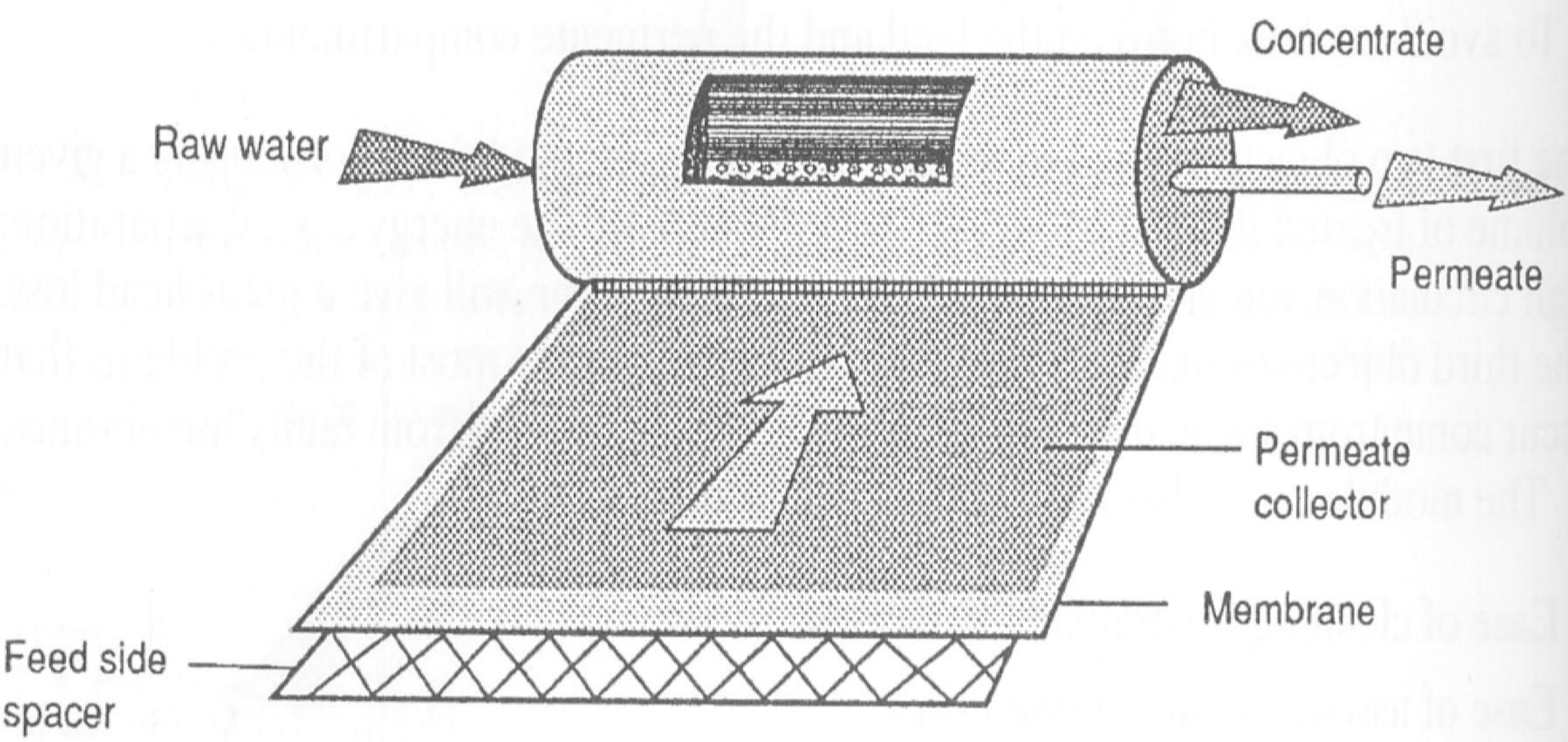
1 Cassette
8 ZeeWeed Modules



20’ Frame
6 cassettes
48
modules

40’ Frame
12
cassettes
96
modules

Module Configuration – Spiral Wound



(b)

Comparison of Membrane Configurations

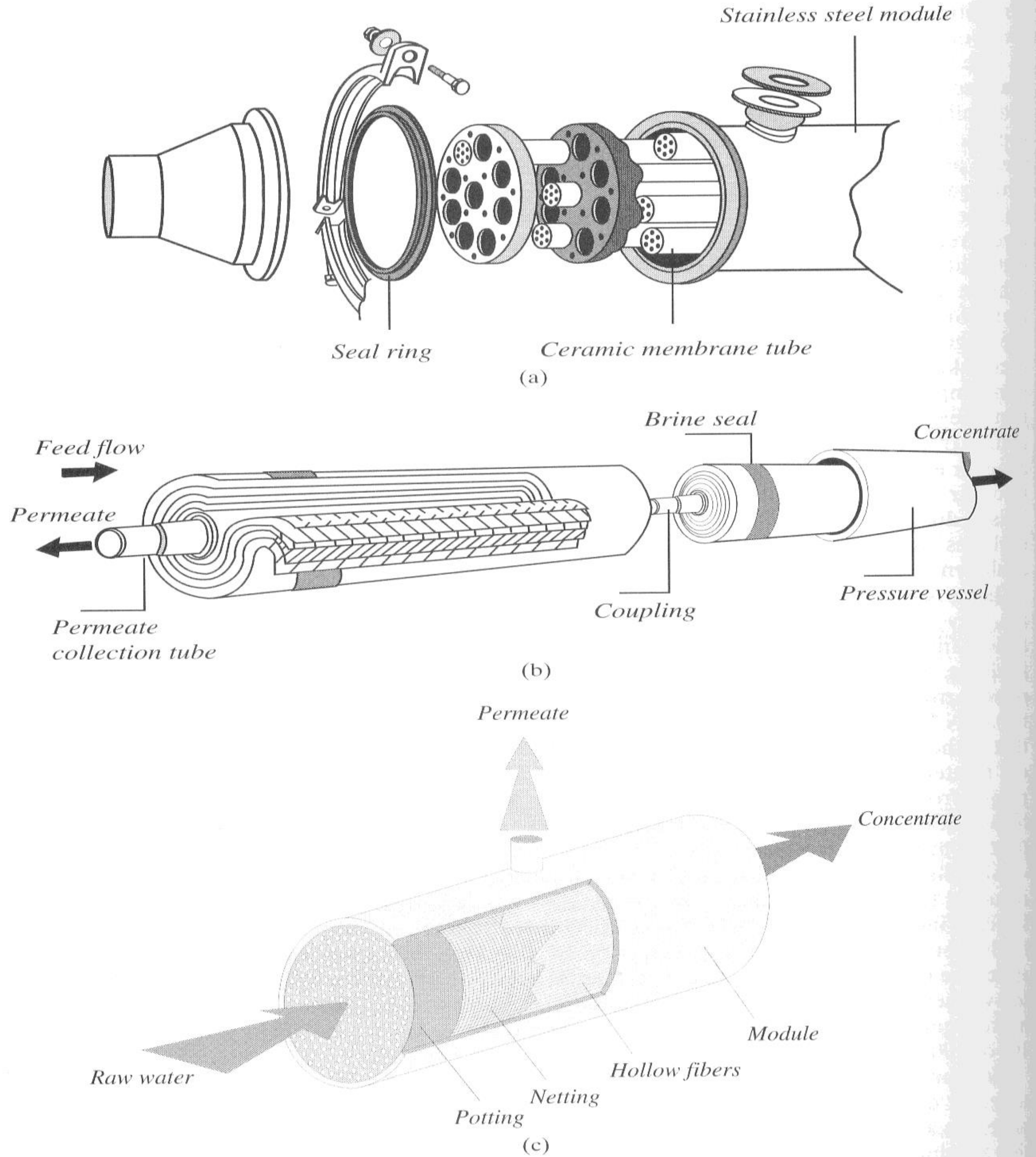


FIGURE 10.7 Comparison of construction characteristics for three types of modules: (*a*) connection of a tubular ceramic module; (*b*) assembly of the spiral-wound RO membrane elements; (*c*) hollow-fiber module—epoxy potting assembly.

Comparison of Different Module Types

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 Classifications

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 Classifications

Separation Mechanisms – Sub Classes

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

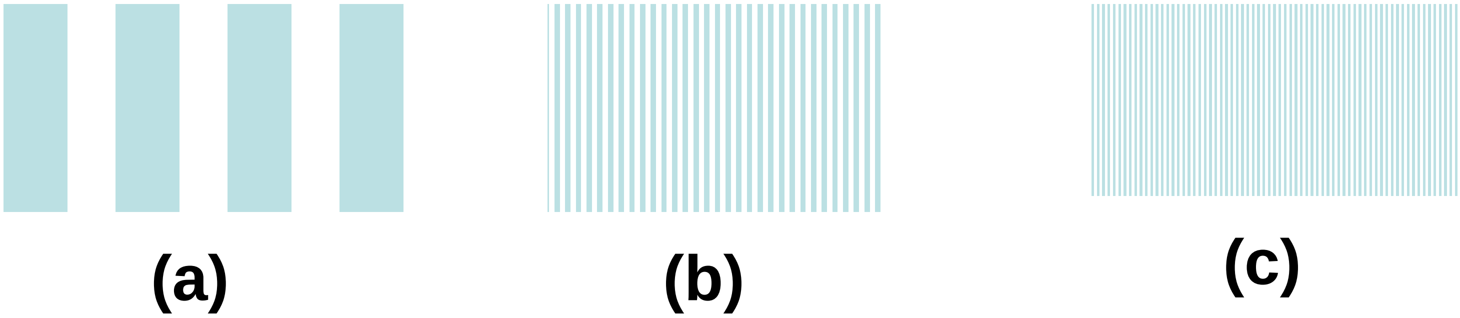
Membrane Classifications Morphology

- Asymmetric membranes
- Composite membranes

Membrane Classifications Morphology

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

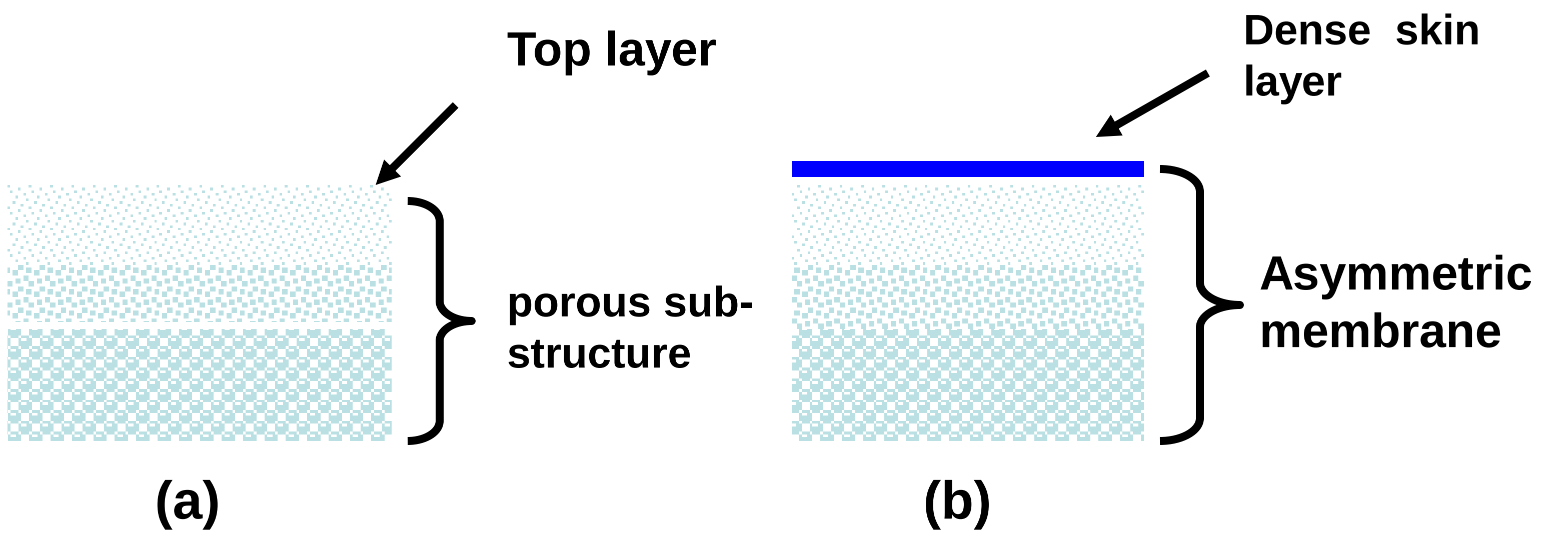
Membrane Morphology



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

Membrane 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

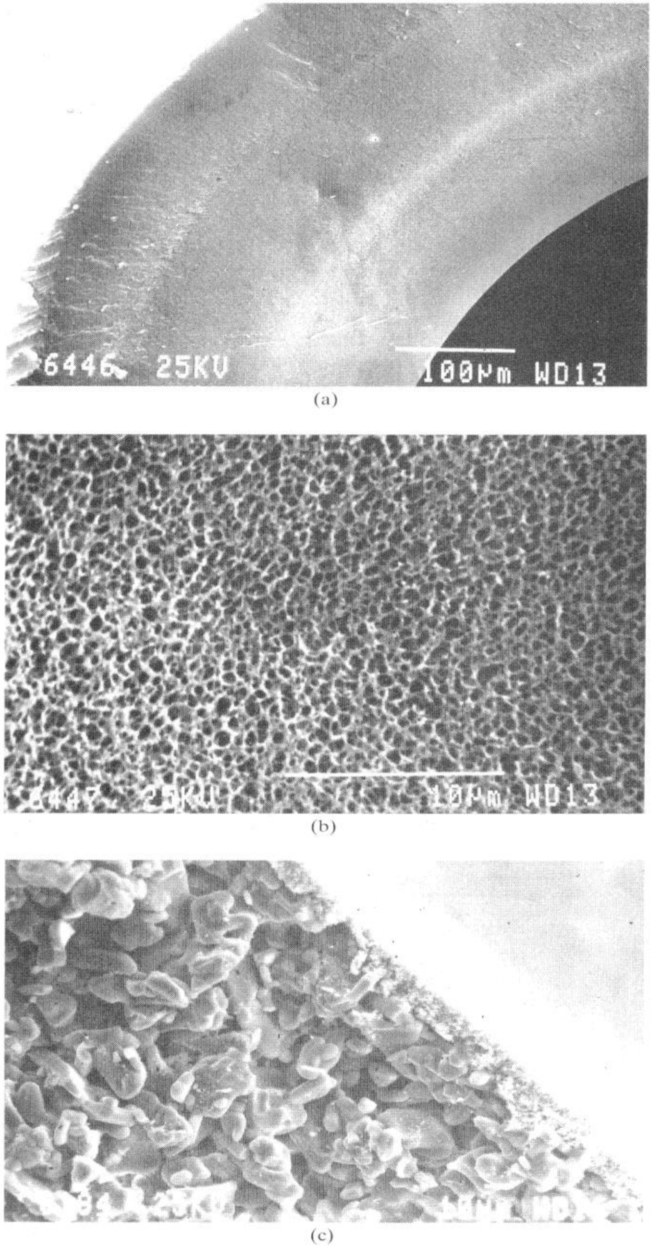


FIGURE 10.5 Modular structure of a UF polymeric: (*a*) and (*b*) Aquasource; and a ceramic membrane (*c*) Techsep.

- Ceramics
- Glass
- Metals
- Polymers

Important Membrane 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

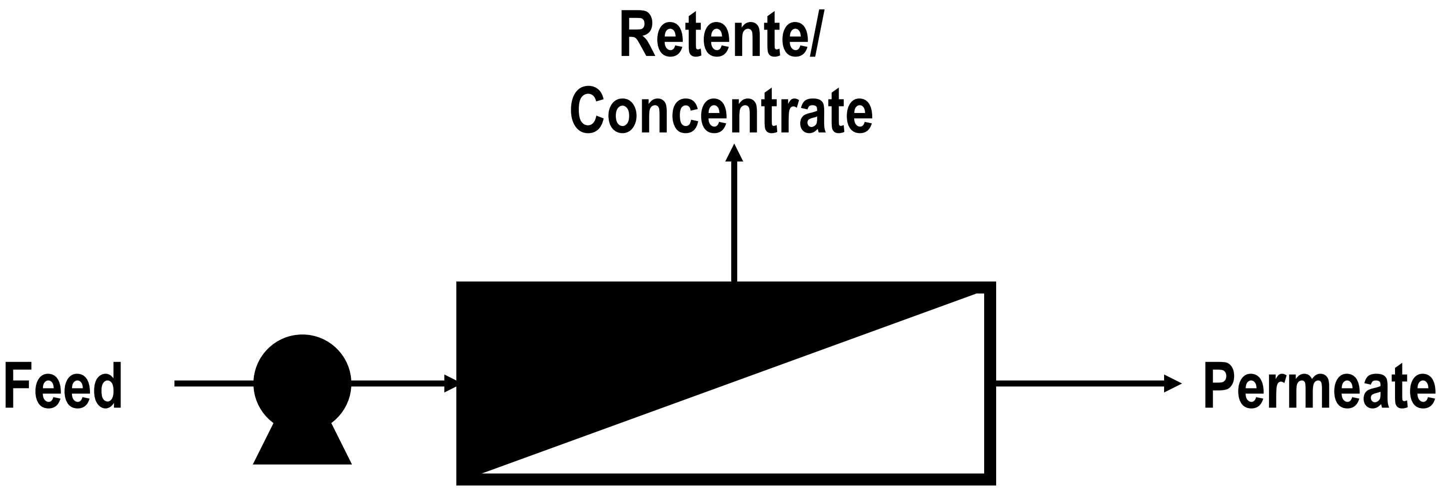
Conventional Modular Package

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

Why Immersed System?

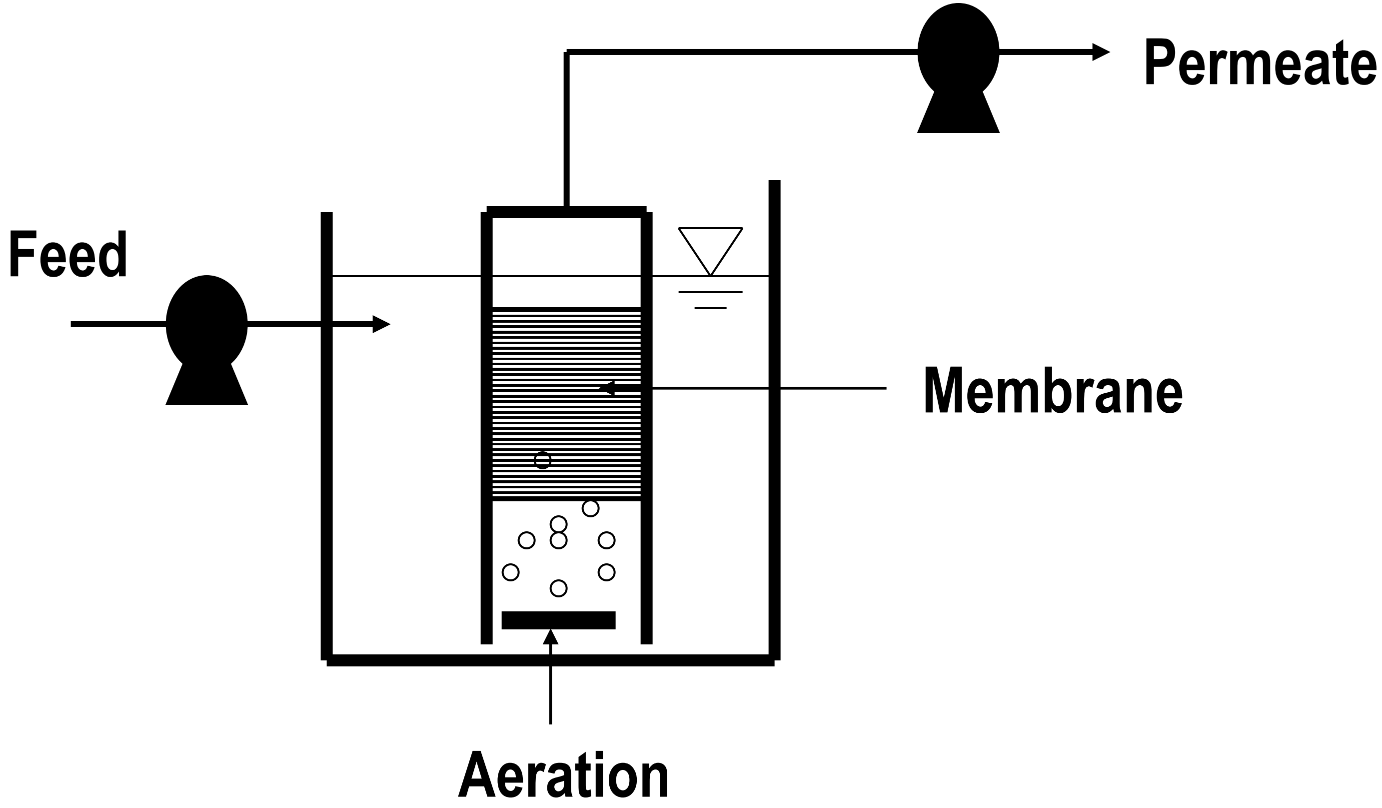
- Low pressure system
- Hybrid with biochemical processes
- Hybrid with chemical processes
- Less fouling problems
- Relatively easier cleaning procedure
- Less sludge or by-products production

Conventional Membrane Package

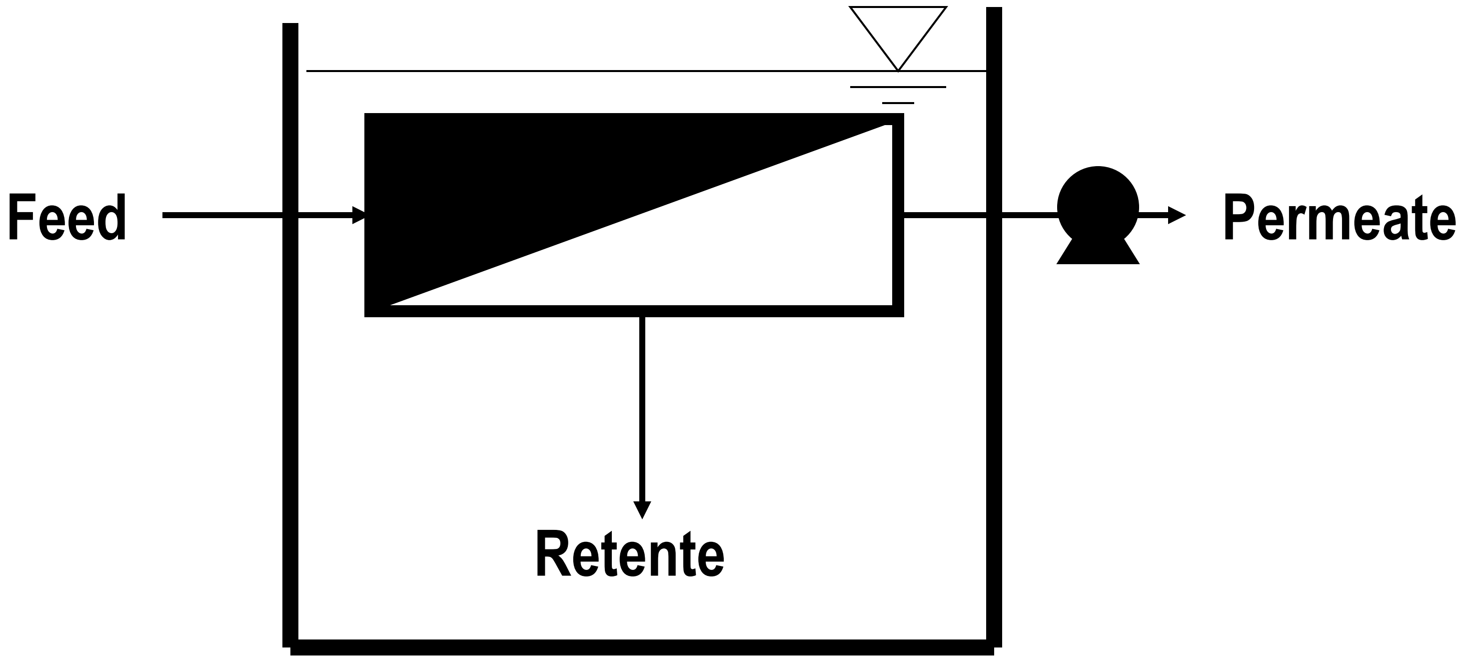


Membrane Plant for Water Treatment, Ogose Town, Japan

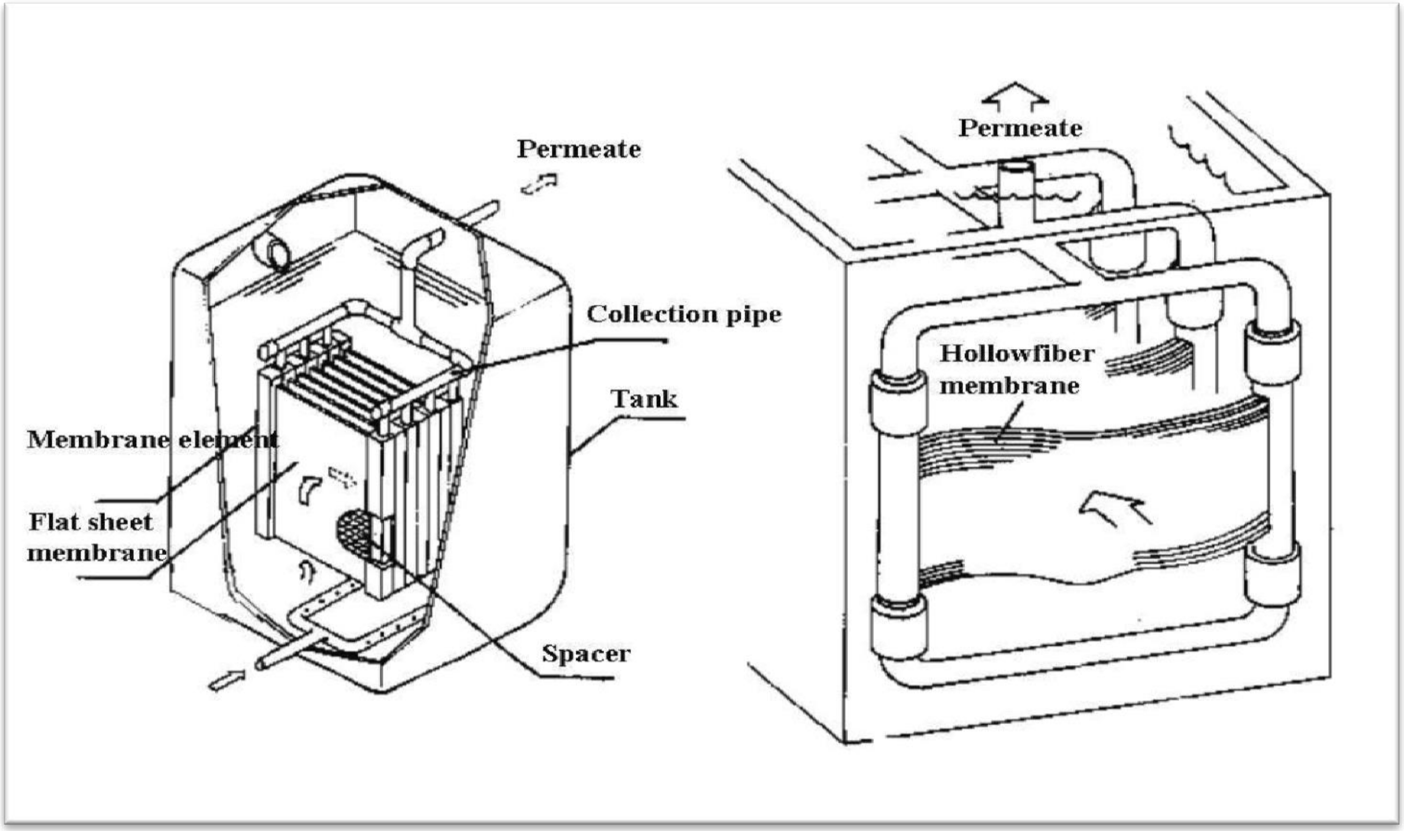
Immersed Membrane Package



Immersed Membrane

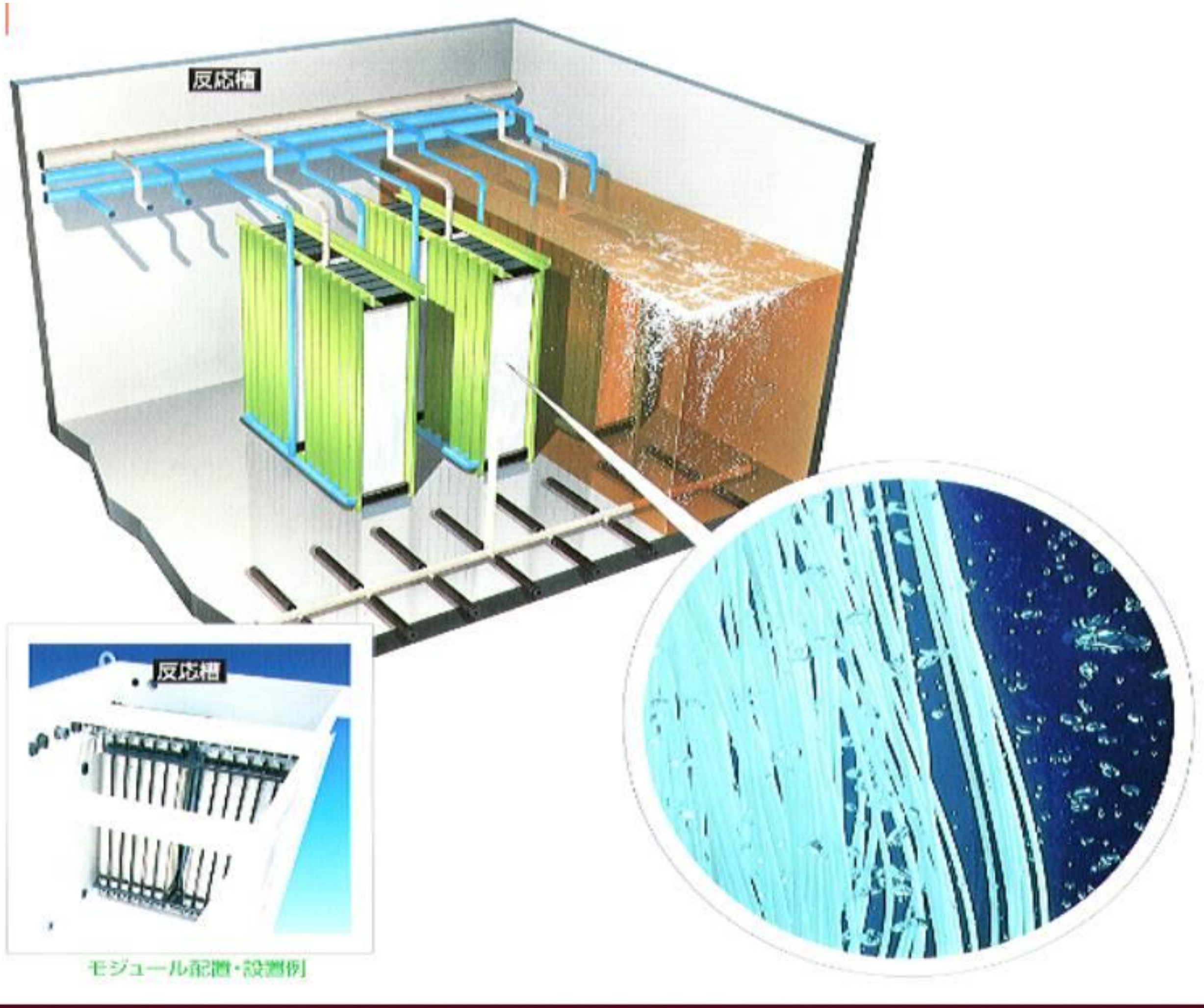


Immersed Membrane

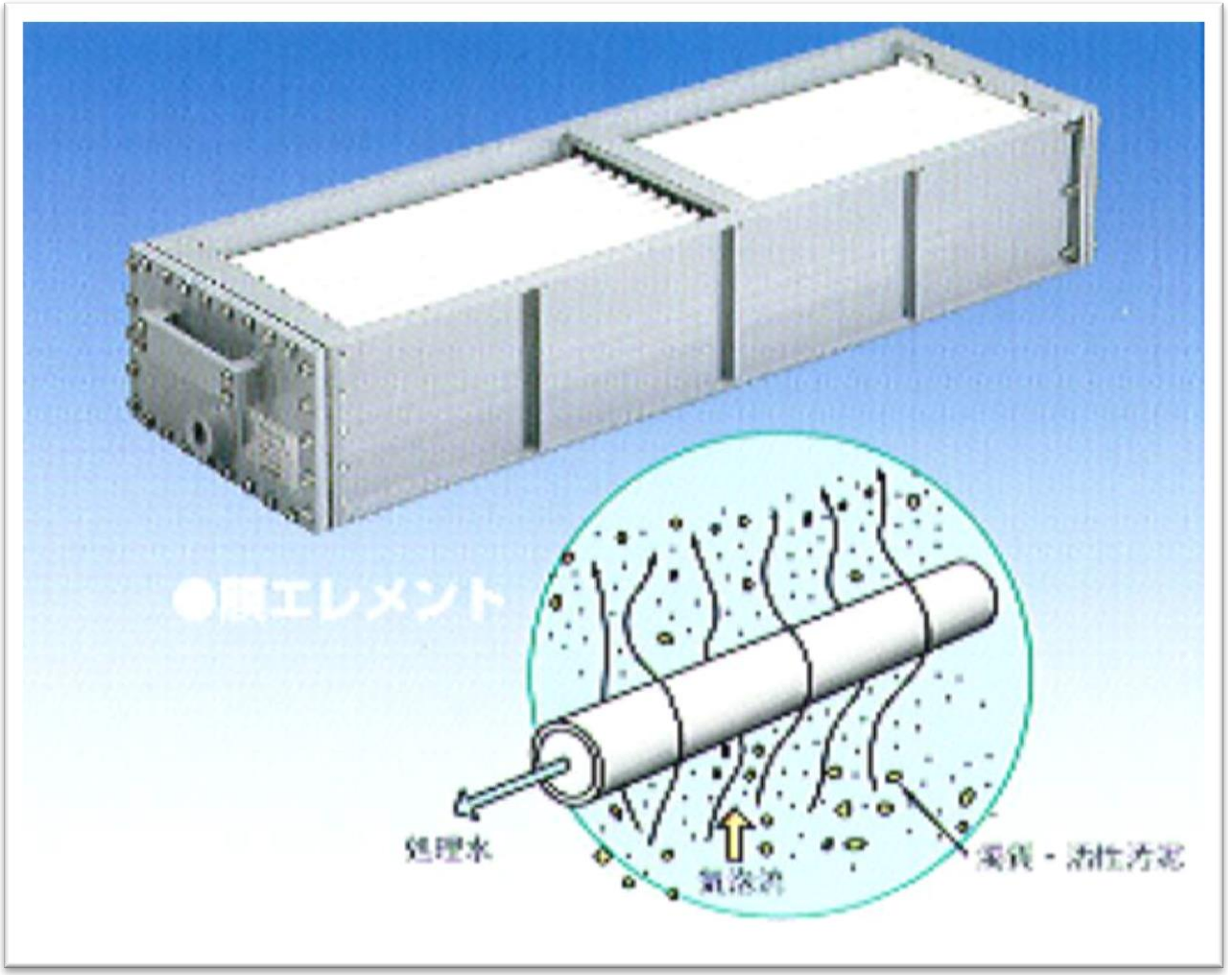


(a) Flat Sheet Membrane **(b) Hollow Fibre Membrane**

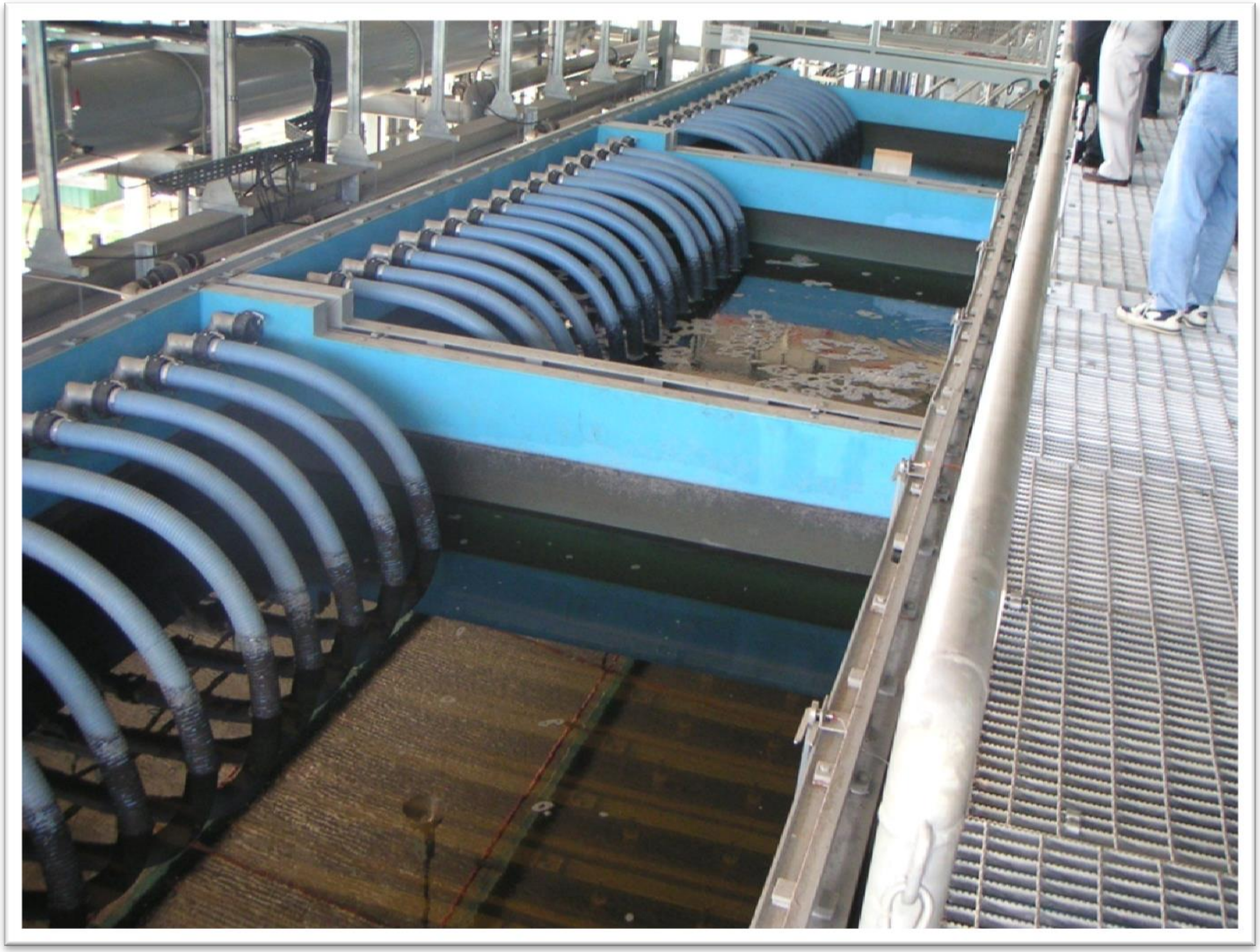
Zenon's MF Hollow-Fibre Module



Kubota's MF Tubular (Ceramic)



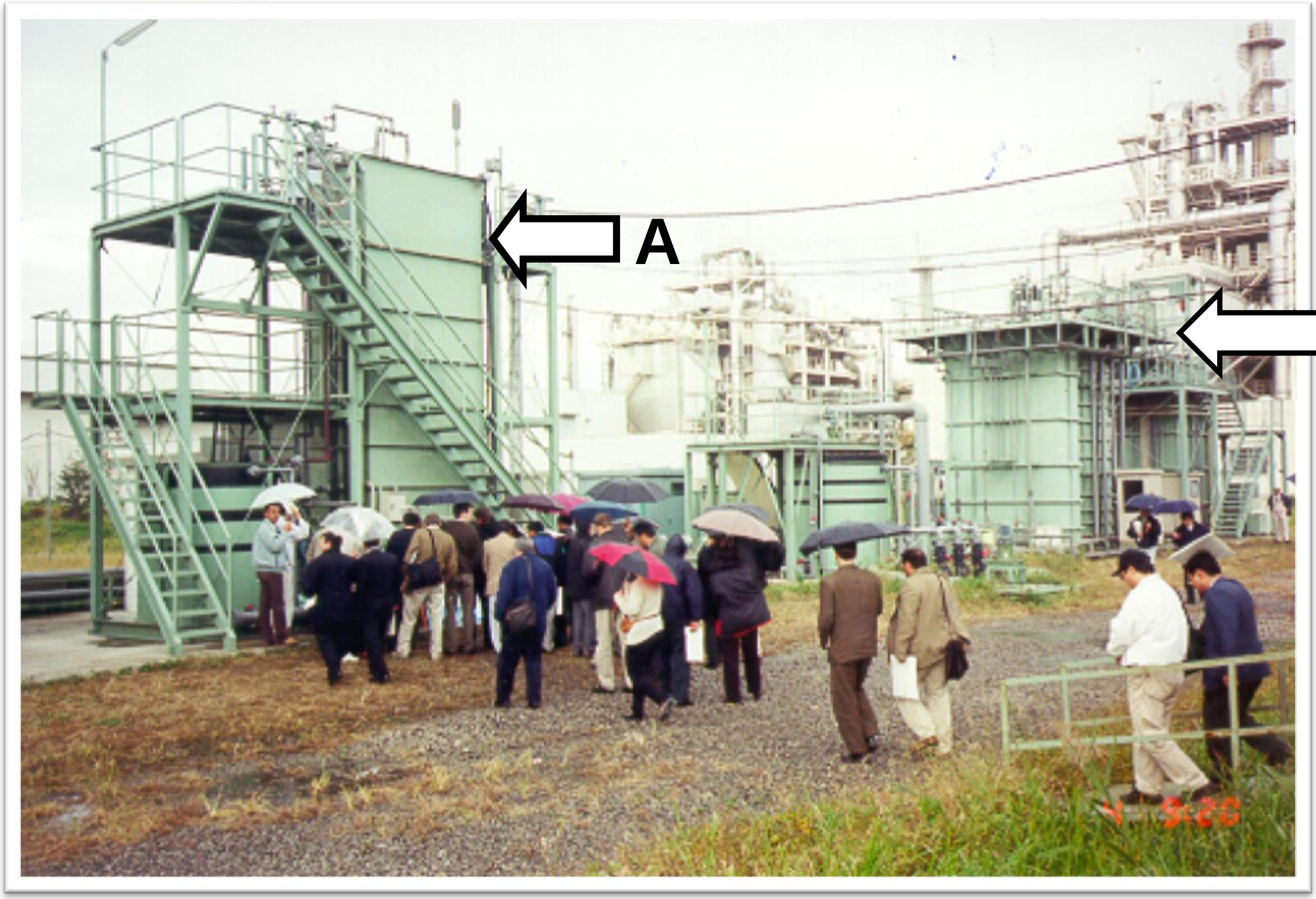
Membrane Bioreactor (MBR)



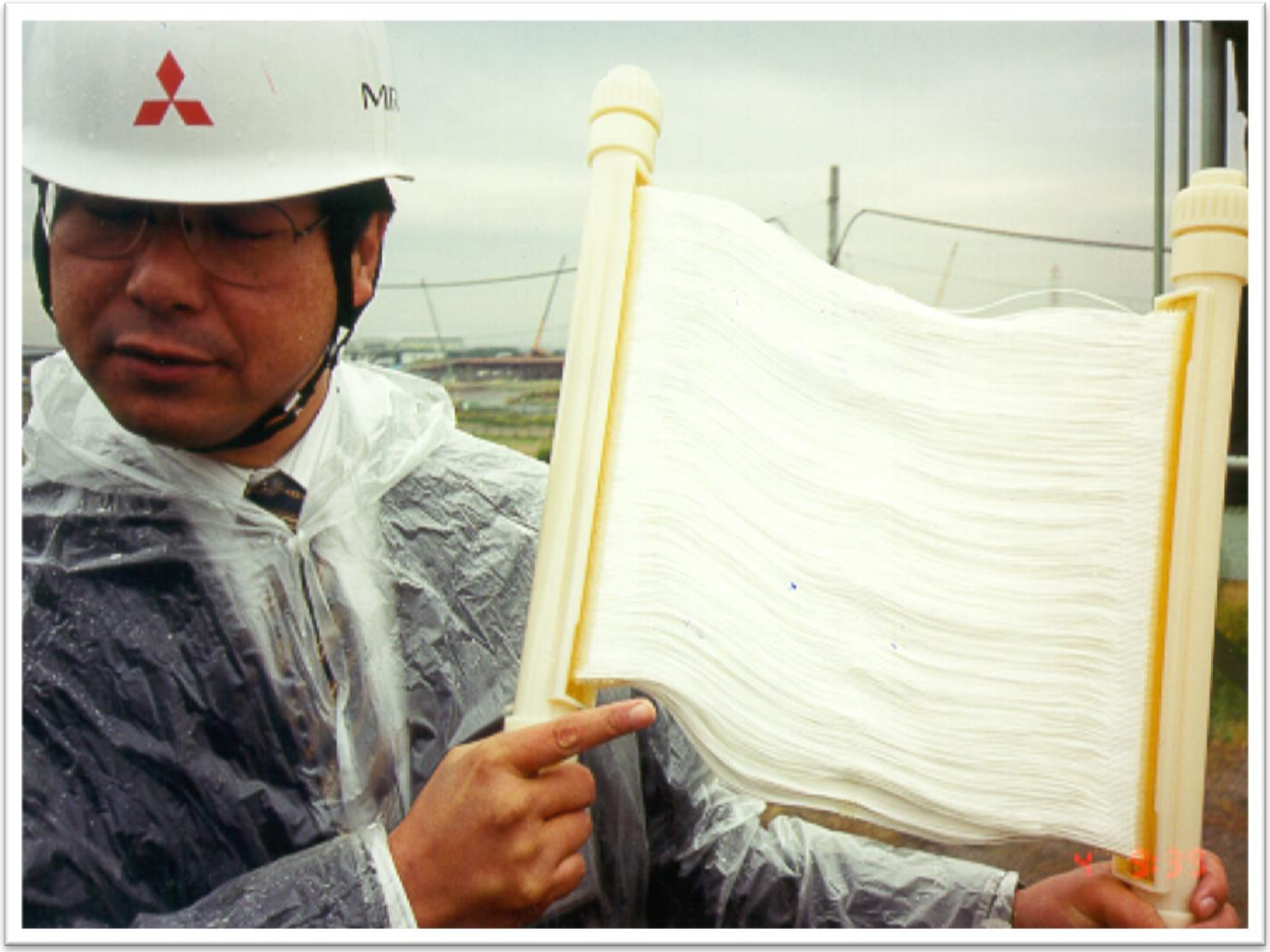
Membrane Bioreactor (MBR)

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

MBR Pilot Plants in Tokyo (A) Mitsubishi; (B) Kubota



MBR by Mitsubishi Rayon Engineering



MBR by Mitsubishi Rayon Engineering, 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

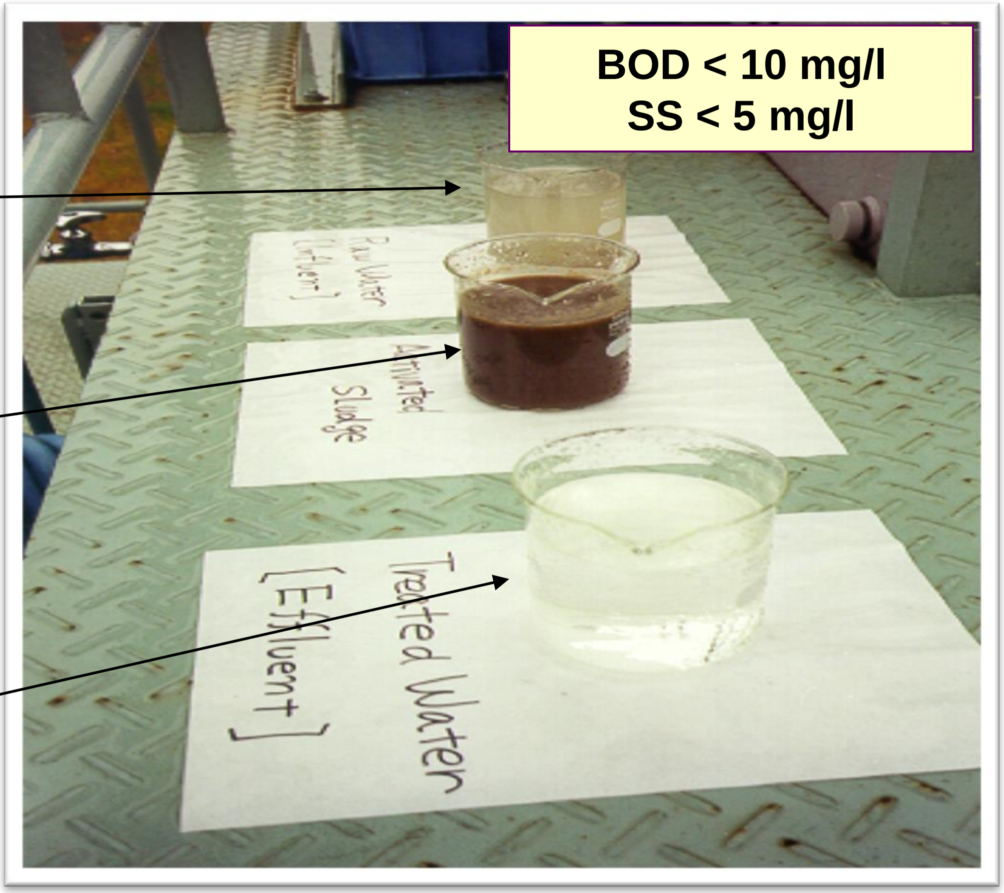
UTM
UNIVERSITI TEKNOLOGI MALAYSIA
www.utm.my

Effluent of MBR from Mitsubishi Pilot Plant

Feed

Activated sludge

Treated effluent



Financial Comparison
MBR vs 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

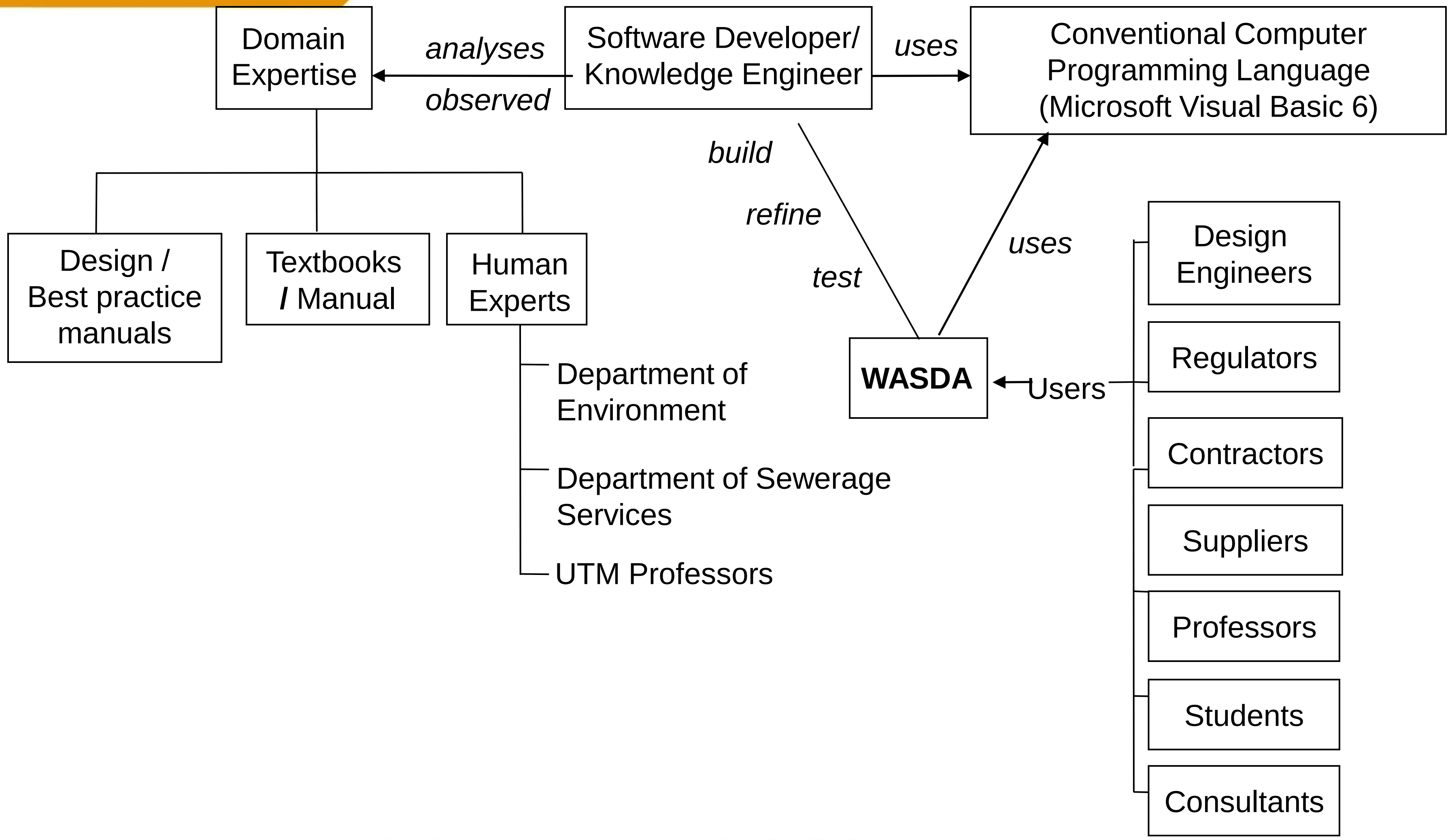
WASDA in Perspective

- 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.

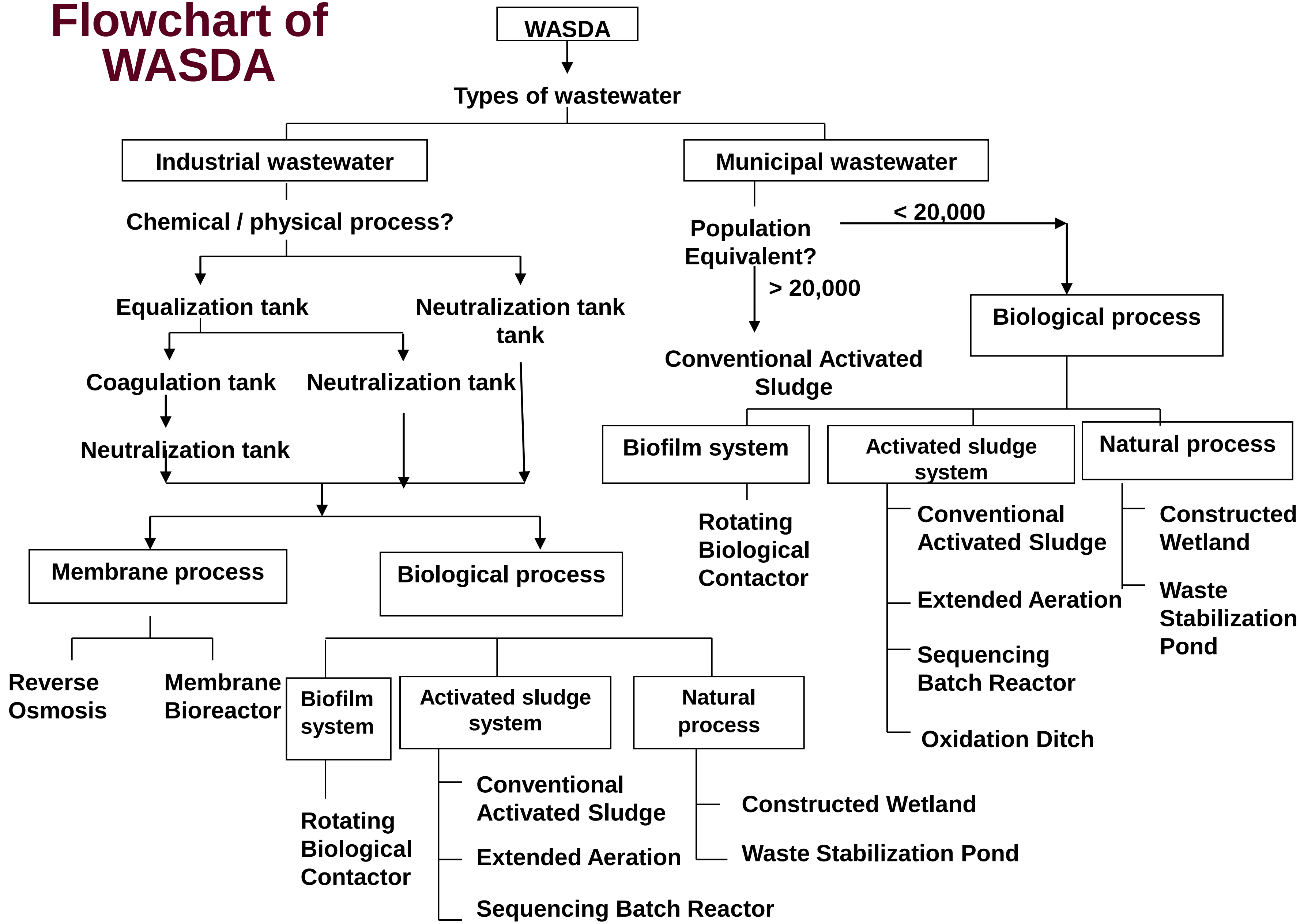
Modules in WASDA

- 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

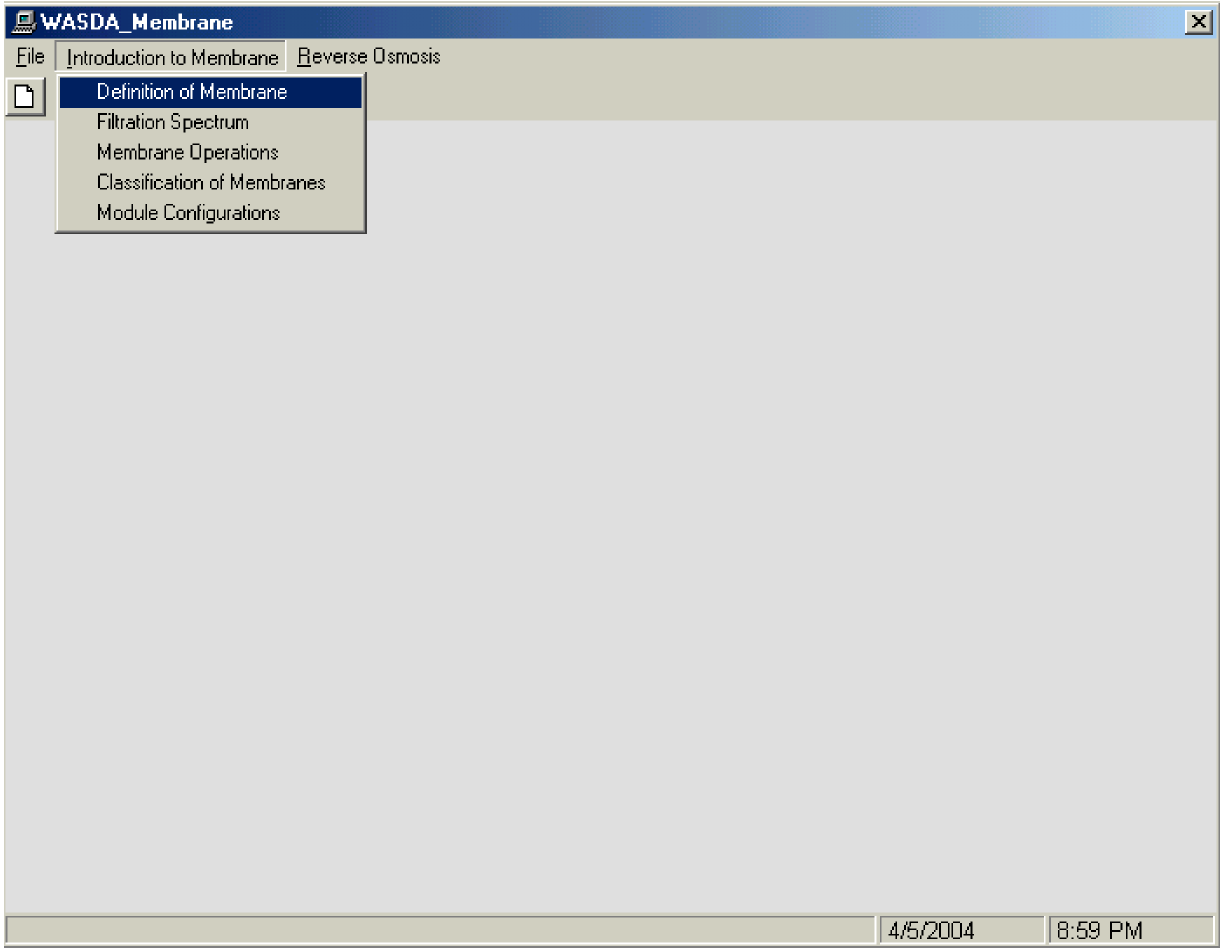
Design advisor or knowledge base forms:

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

Computerized design spreadsheet

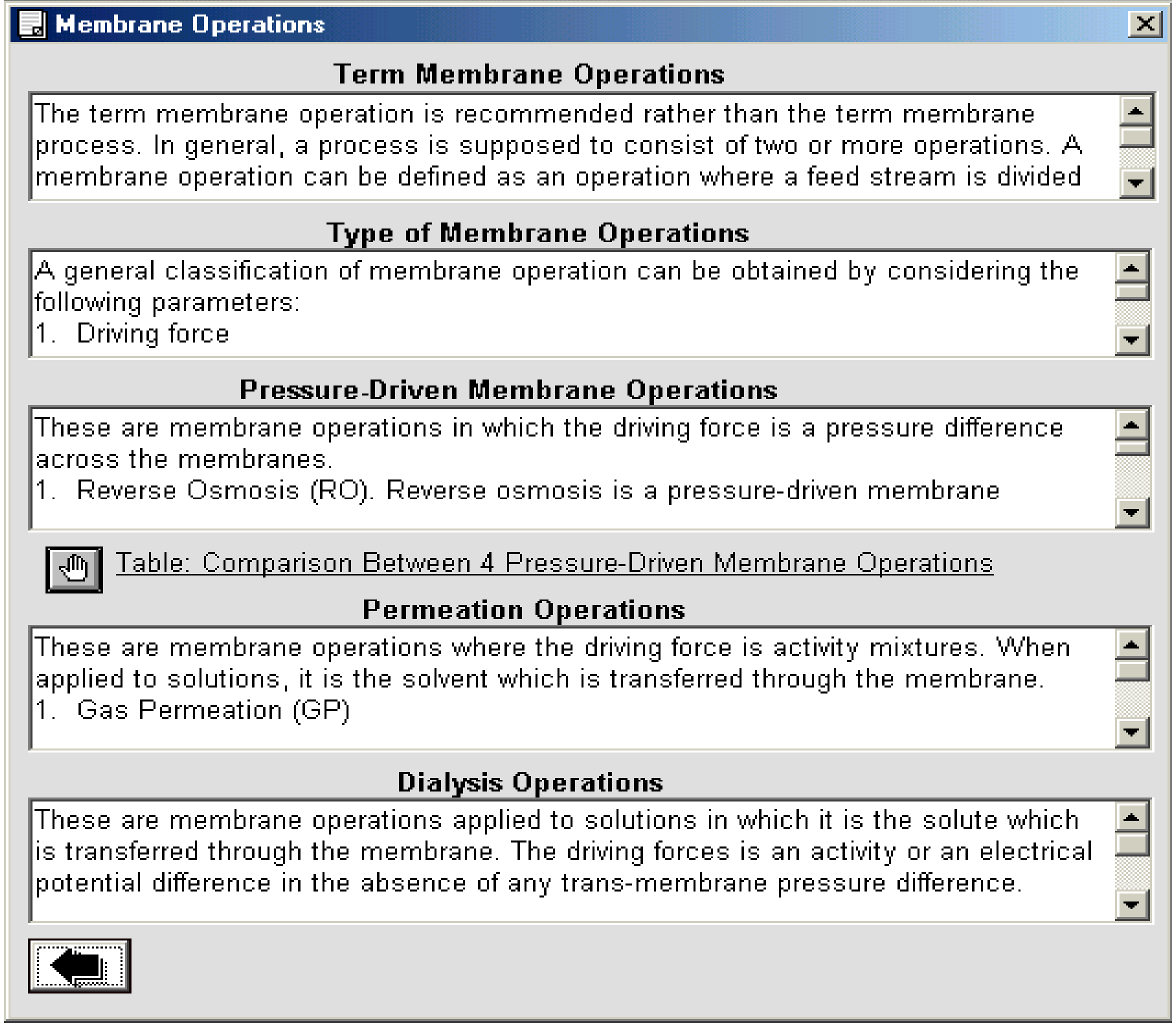
Forms in Membrane - RO Module

Main form of Membrane module



Forms in Membrane - RO Module

Membrane operations form


Membrane Operations

Term Membrane Operations

The term membrane operation is recommended rather than the term membrane process. In general, a process is supposed to consist of two or more operations. A membrane operation can be defined as an operation where a feed stream is divided

Type of Membrane Operations

A general classification of membrane operation can be obtained by considering the following parameters:
1. Driving force

Pressure-Driven Membrane Operations

These are membrane operations in which the driving force is a pressure difference across the membranes.
1. Reverse Osmosis (RO). Reverse osmosis is a pressure-driven membrane

Table: Comparison Between 4 Pressure-Driven Membrane Operations

Permeation Operations

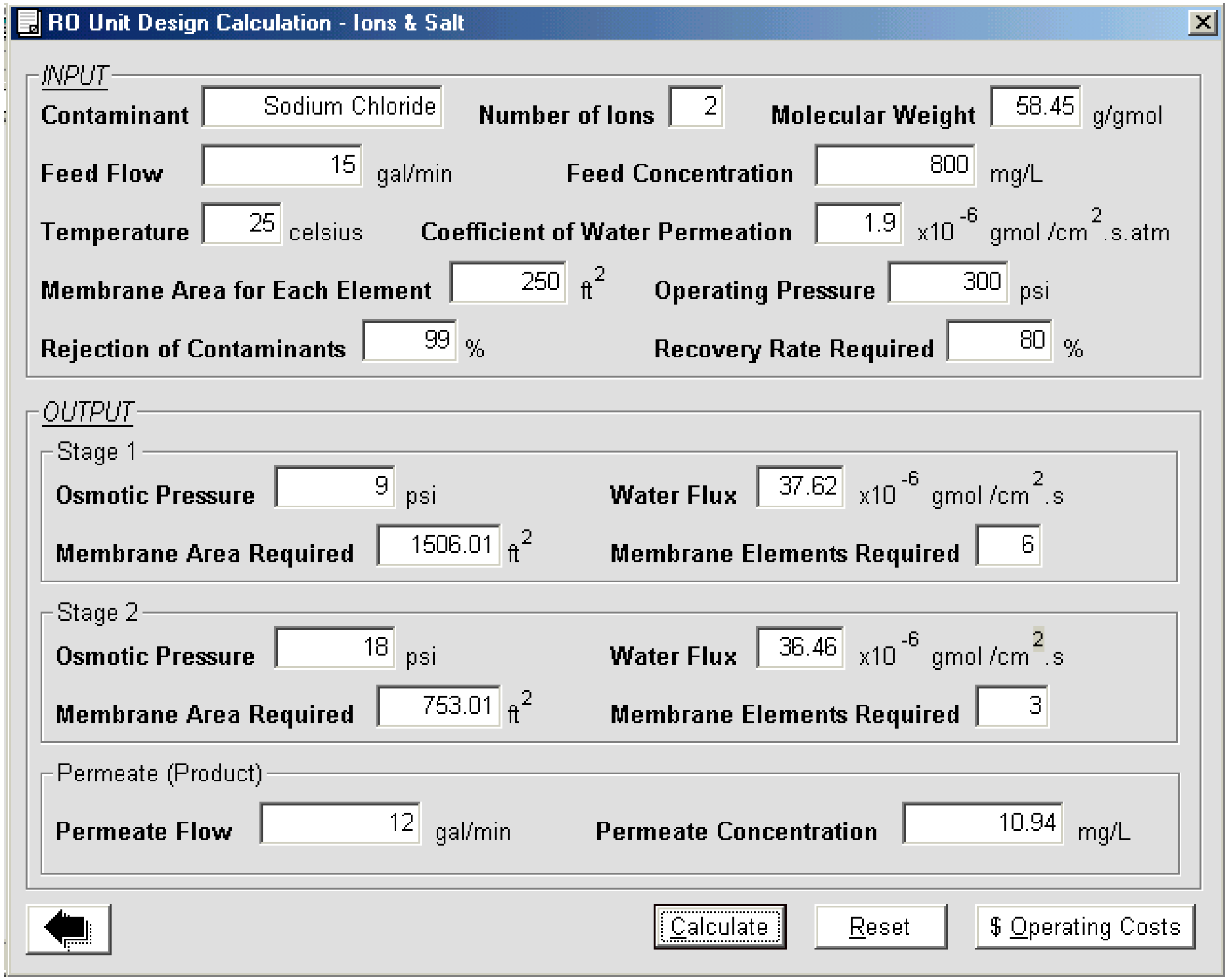
These are membrane operations where the driving force is activity mixtures. When applied to solutions, it is the solvent which is transferred through the membrane.
1. Gas Permeation (GP)

Dialysis Operations

These are membrane operations applied to solutions in which it is the solute which is transferred through the membrane. The driving forces is an activity or an electrical potential difference in the absence of any trans-membrane pressure difference.

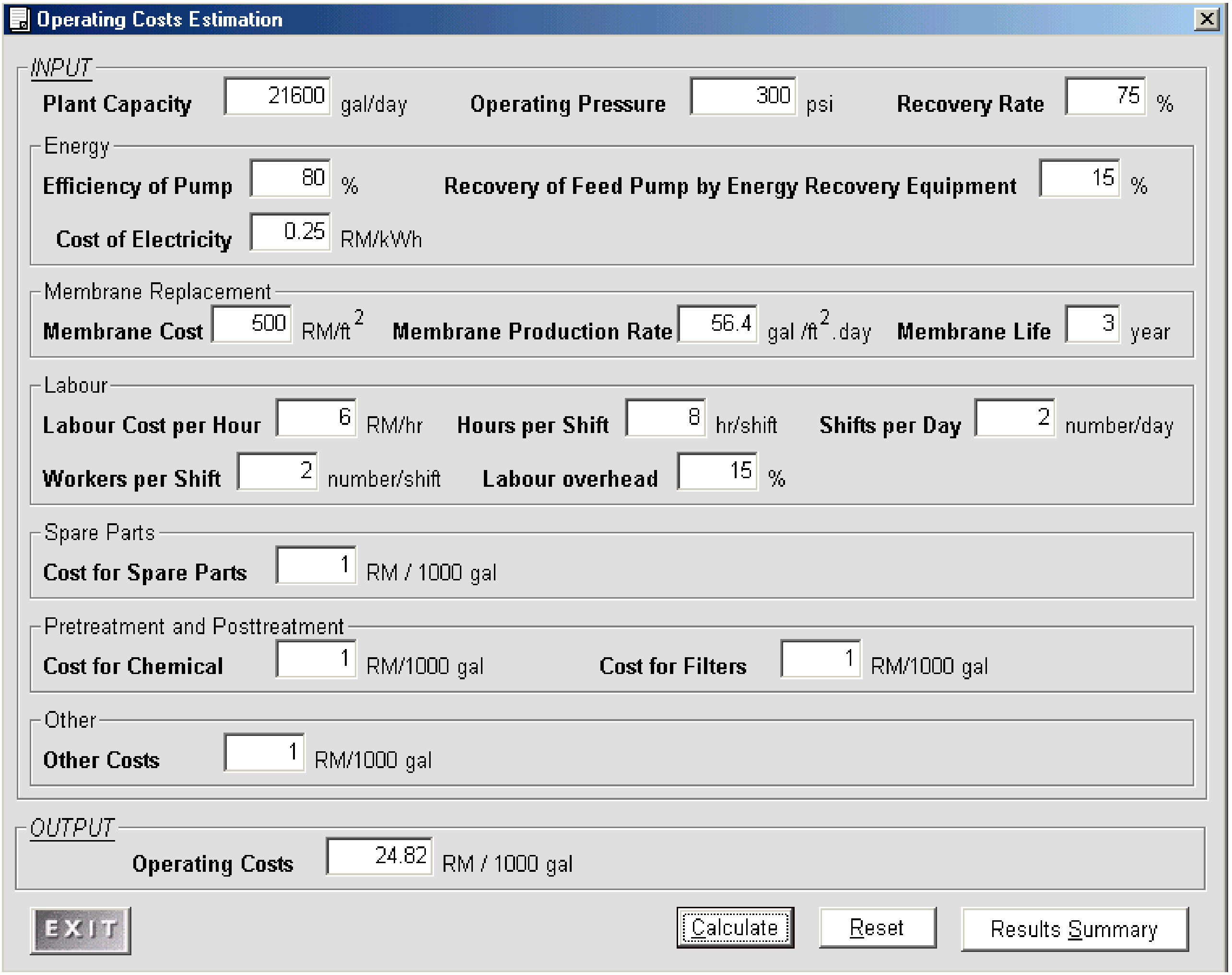
Forms in Membrane - RO Module

RO Unit Design Calculation form



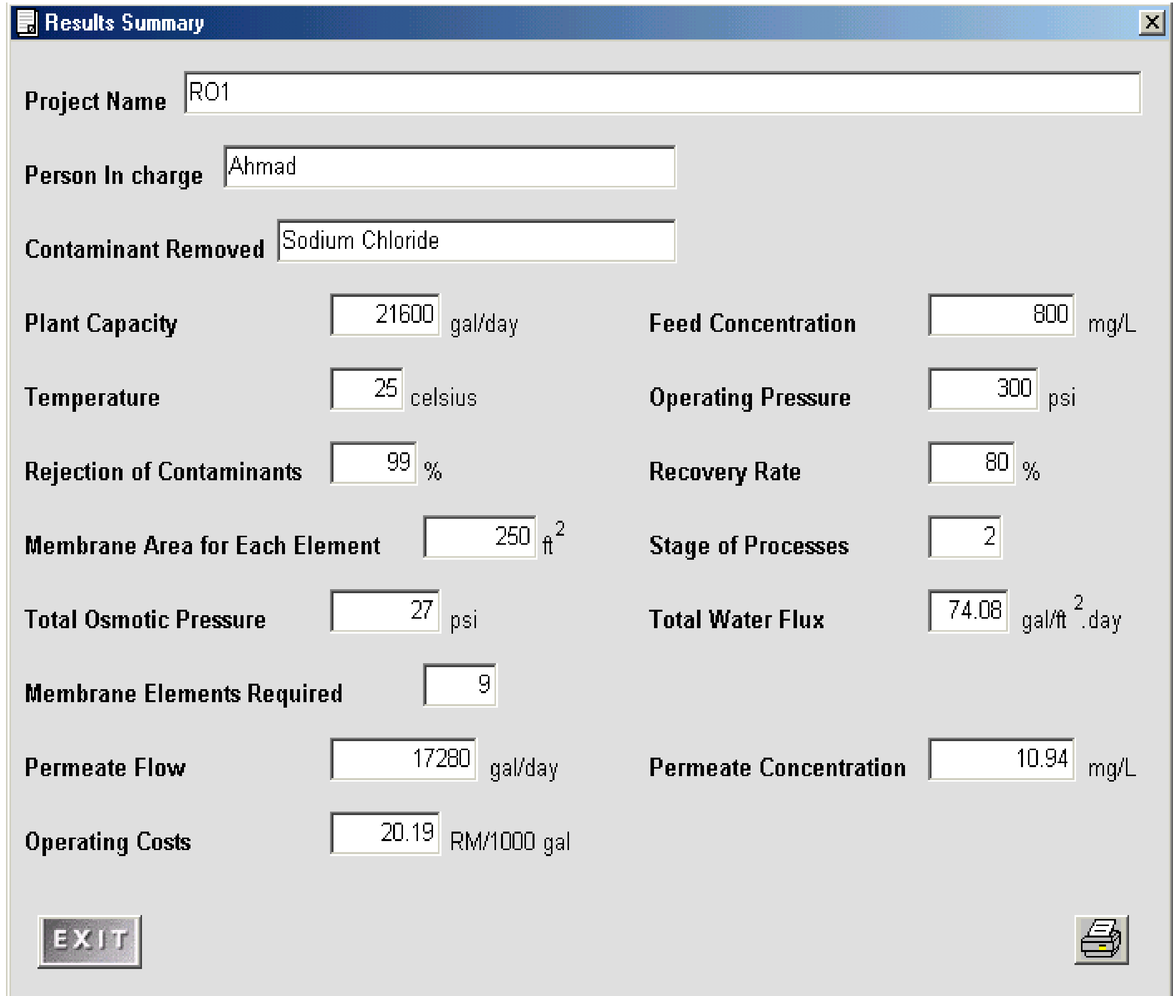
Forms in Membrane - RO Module

Operating cost estimation form



Forms in Membrane - RO Module

Result summary form


Results Summary

Project Name	RO1		
Person In charge	Ahmad		
Contaminant Removed	Sodium Chloride		
Plant Capacity	21600 gal/day	Feed Concentration	800 mg/L
Temperature	25 celsius	Operating Pressure	300 psi
Rejection of Contaminants	99 %	Recovery Rate	80 %
Membrane Area for Each Element	250 ft^2	Stage of Processes	2
Total Osmotic Pressure	27 psi	Total Water Flux	74.08 $gal/ft^2.day$
Membrane Elements Required	9		
Permeate Flow	17280 gal/day	Permeate Concentration	10.94 mg/L
Operating Costs	20.19 RM/1000 gal		

EXIT

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.