2. History of Membrane Development and Mass Transfer Modelling

(Takeshi Matsuura, Prof. Matsuura, IMRI,
Univ. of Ottawa)

HISTORY OF MEMBRANE DEVELOPMENT

Presented at

The Fourth Membrane Society of Korea Workshop

By

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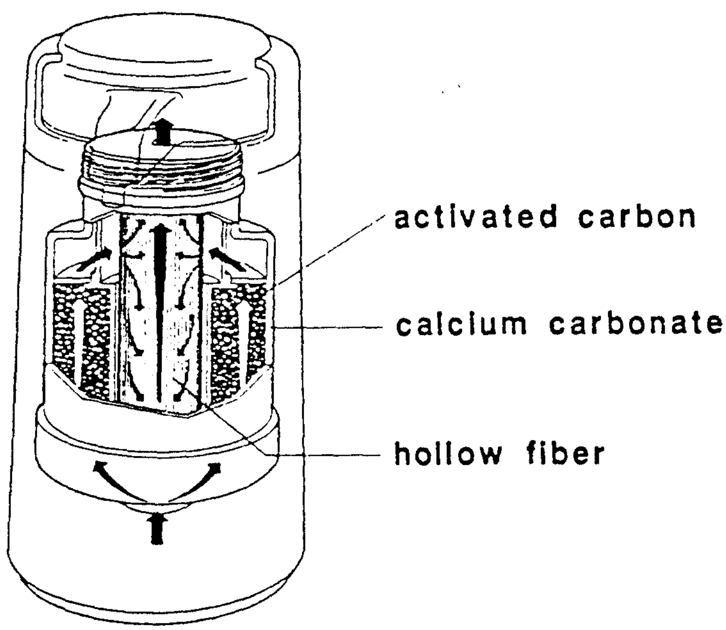
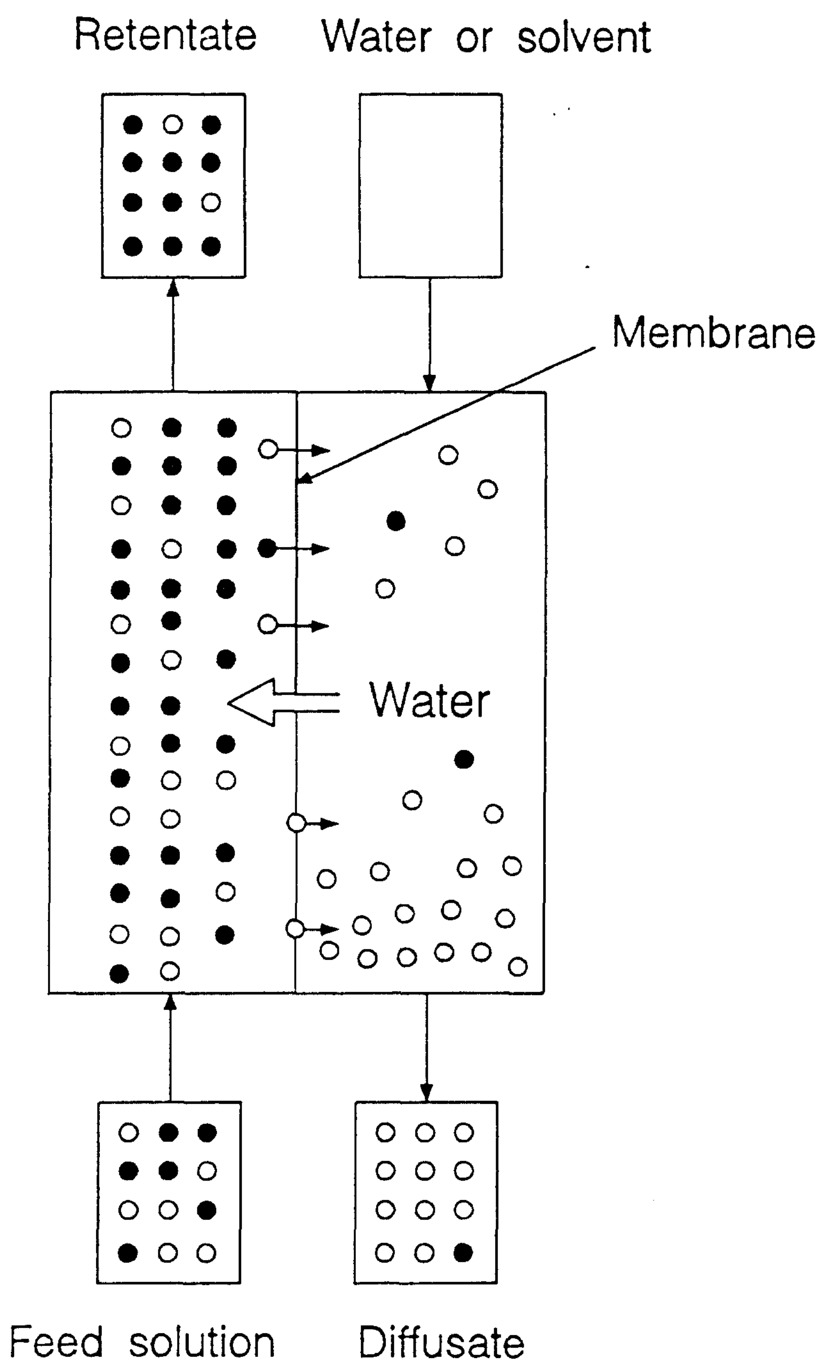
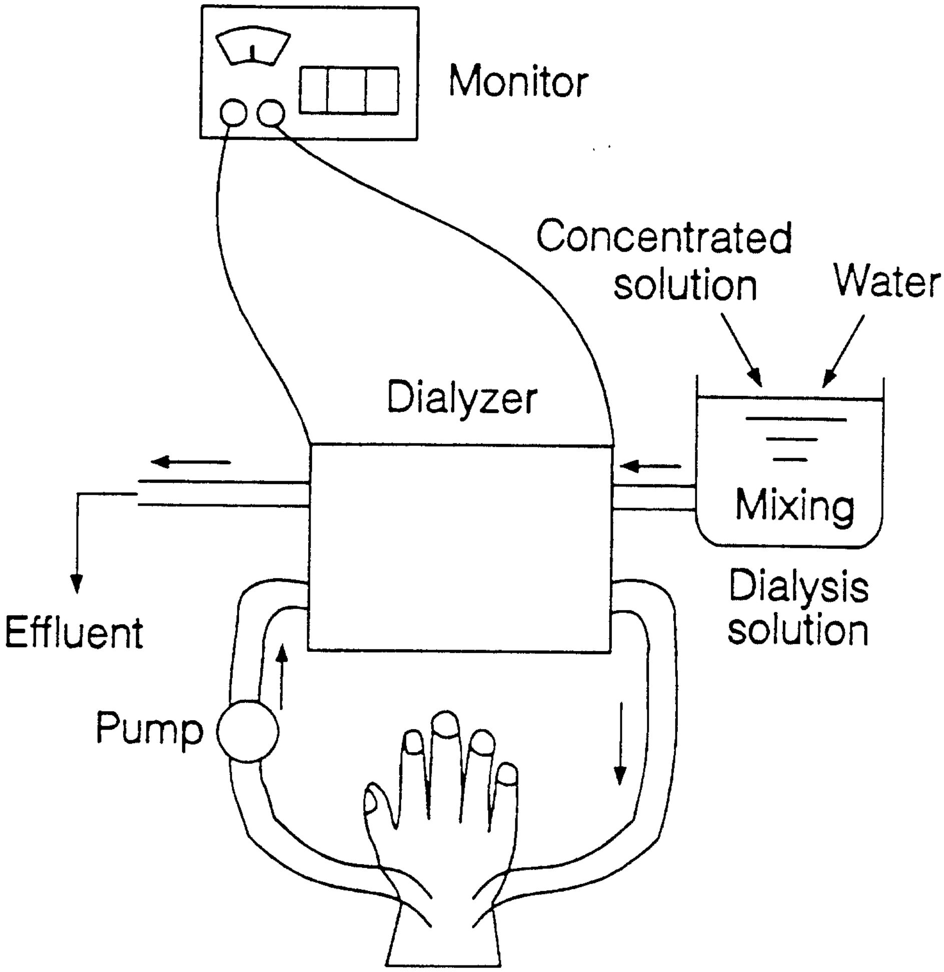
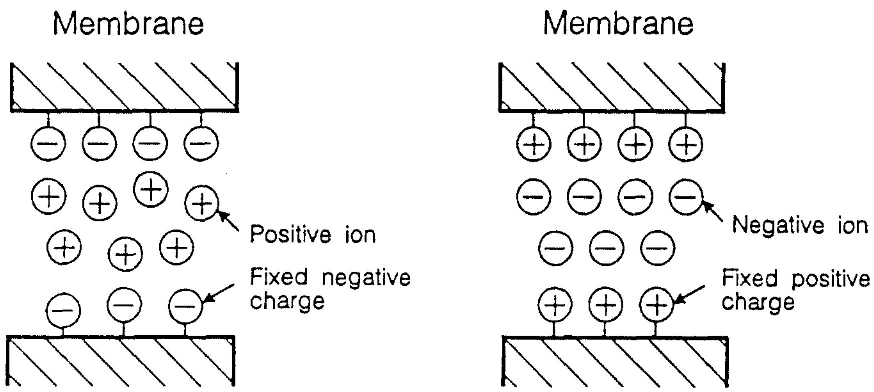
History of Membrane Process Development

Process	Year	Name
microfiltration	1920	Zsigmondy
ultrafiltration	1930	
hemodialysis	1950	Kolff
electrodialysis	1955	
reverse osmosis	1960	Loeb, Sourirajan
ultrafiltration	1960	
gas separation	1979	Henis, Tripodi
pervaporation	1982	Tusel

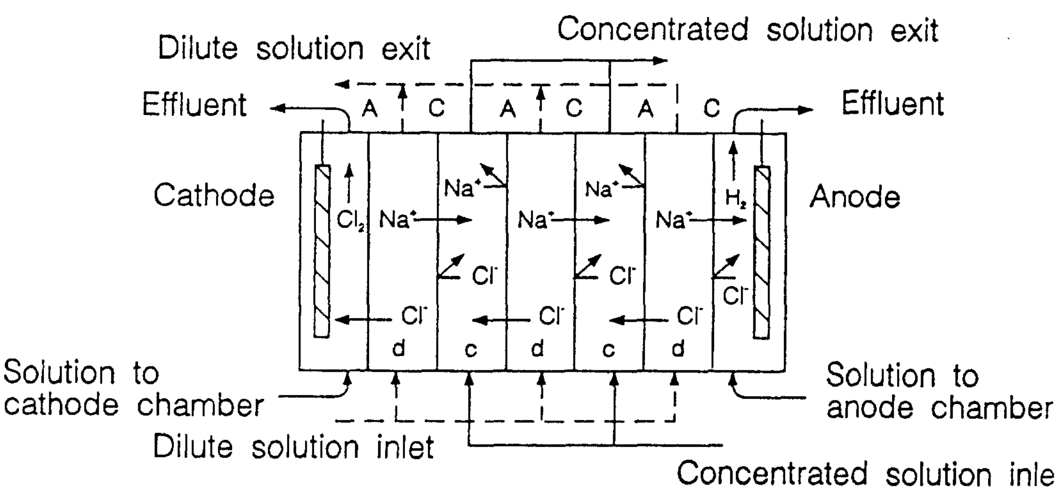

activated carbon
calcium carbonate
hollow fiber


Retentate
Water or solvent
Membrane
Water
Feed solution
Diffusate

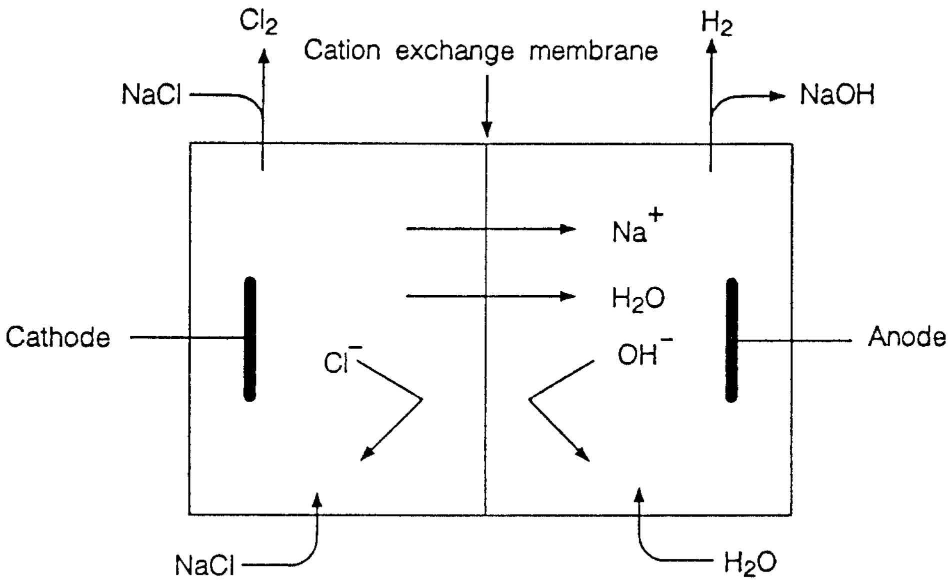

Monitor
Concentrated solution
Water
Dialyzer
Mixing
Dialysis solution
Effluent
Pump

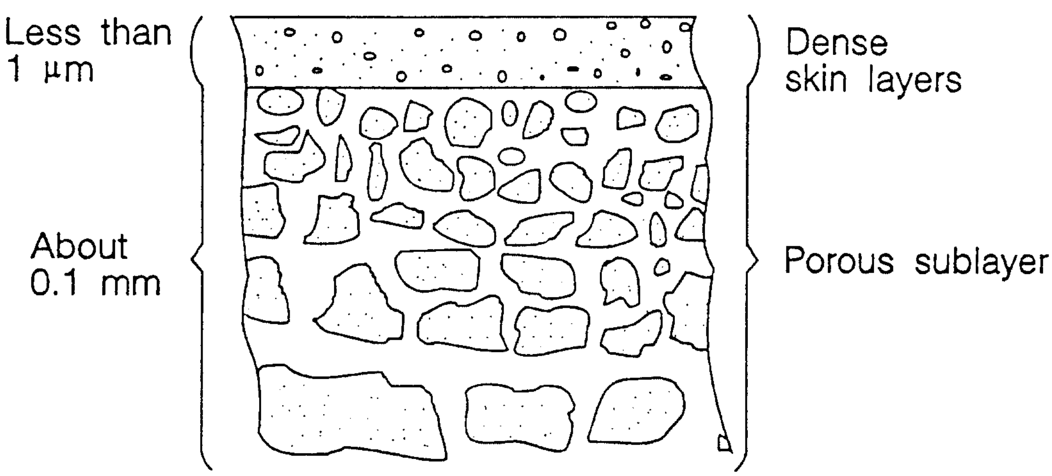


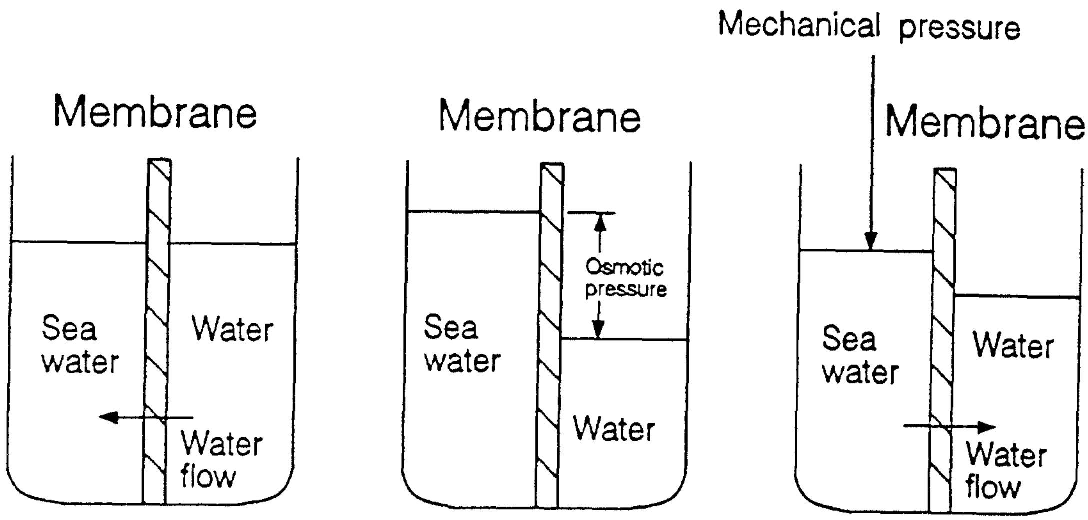
(a) Cation exchange membrane   (b) Anion exchange membrane



A: anion exchange membrane
C: cation exchange membrane
d: dilute solution chamber
c: concentrated solution chamber


Cl_2
Cation exchange membrane
H_2
NaCl
NaOH
Na^+
H_2O
Cathode
Cl^-
OH^-
Anode
NaCl
H_2O


Less than 1 μm
Dense skin layers
About 0.1 mm
Porous sublayer



(a) Osmosis (b) Osmotic equilibrium (c) Reverse osmosis

Gibbs Adsorption Isotherm

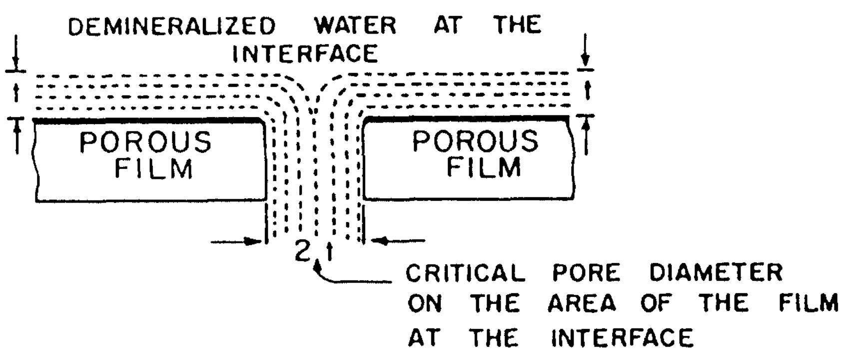
Table I
Some Physicochemical Data Pertinent to Sodium Chloride Solution

Molality (m)	Activity coefficient (α)	Density (ρ), $\times 10^{-3}$, kg/m^3	Surface tension (γ) $\times 10^3$, J/m^2
0.00	-	-	72.80
0.2010	0.751	1.00675	73.17
0.5030	0.688	1.01876	73.71
1.0204	0.650	1.0385	74.515
2.0988	0.614	1.06984	76.27
3.1920	0.714	1.1152	78.08
4.3628	0.790	1.1507	80.02
4.9730	0.848	1.1679	81.09
5.5410	0.874	1.1947	82.17

Table II
Physicochemical Data of Sodium Chloride Solution Based on the Data Given in Table I

αm, mol/kg	$\gamma \times 10^3$, J/m^2	$\frac{d\gamma}{d(\alpha m)} \times 10^3$	α	$\rho \times 10^{-3}$, kg/m^3	m, mol/kg	$t_i \times 10^{10}$, m
0	72.80	2.74[a]	1.0	1.0	0	5.62
0.5	74.16	2.70	0.669	1.024	0.747	3.78
1.0	75.50	2.52	0.624	1.056	1.603	3.35
1.5	76.68	2.15	0.616	1.081	2.435	2.87
2.0	77.65	1.82	0.640	1.103	3.125	2.57
2.5	78.50	1.67	0.685	1.122	3.650	2.54
3.0	79.32	1.62	0.745	1.139	4.027	2.68
3.5	80.12	1.58	0.795	1.152	4.403	2.82
4.0	80.90	1.49	0.833	1.164	4.802	2.79
4.5	81.61	1.35[b]	0.861	1.179	5.226	2.64

a. Calculated as $-3 \times 72.80 + 4 \times 74.16 - 75.50 = 2.74$
b. Calculated as $80.12 - 4 \times 80.9 + 3 \times 81.61 = 1.35$



Module Development

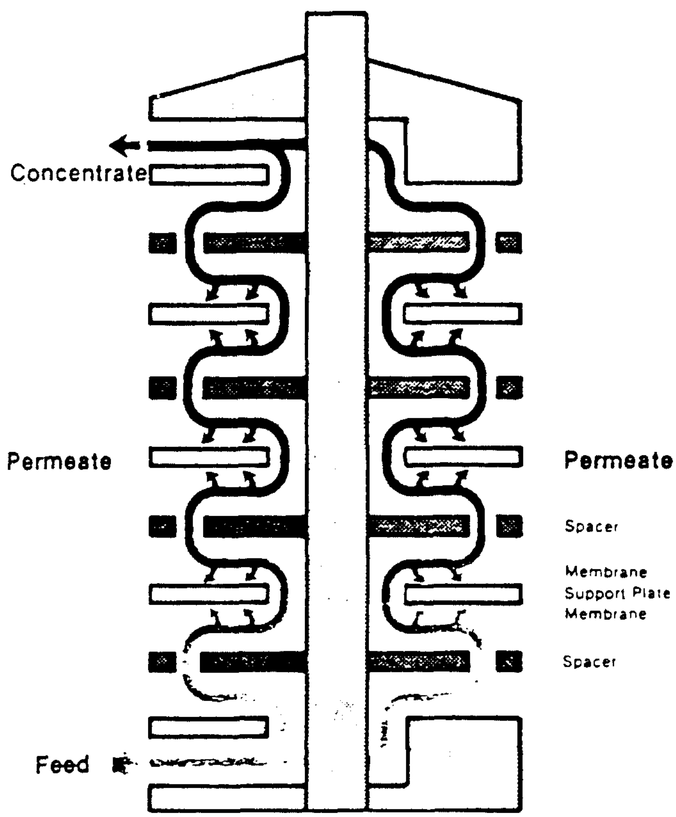
> Plate and Frame

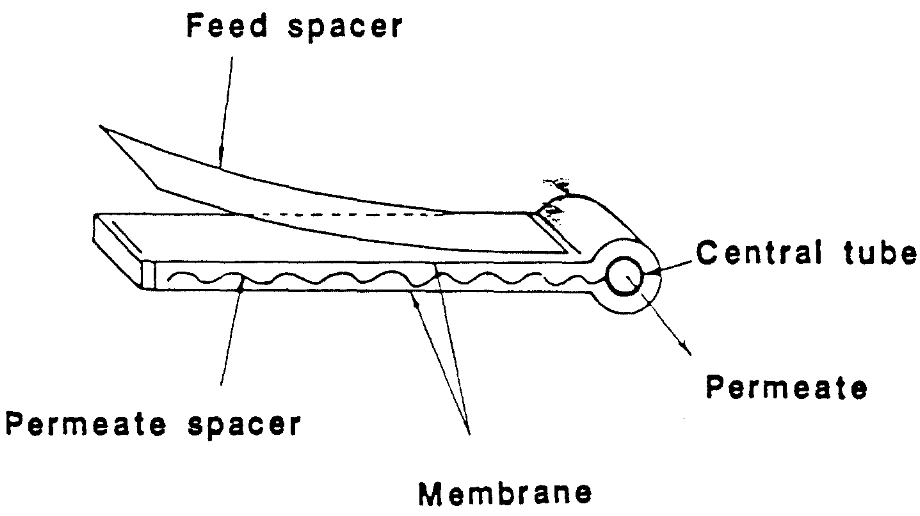
> Spiral Wound

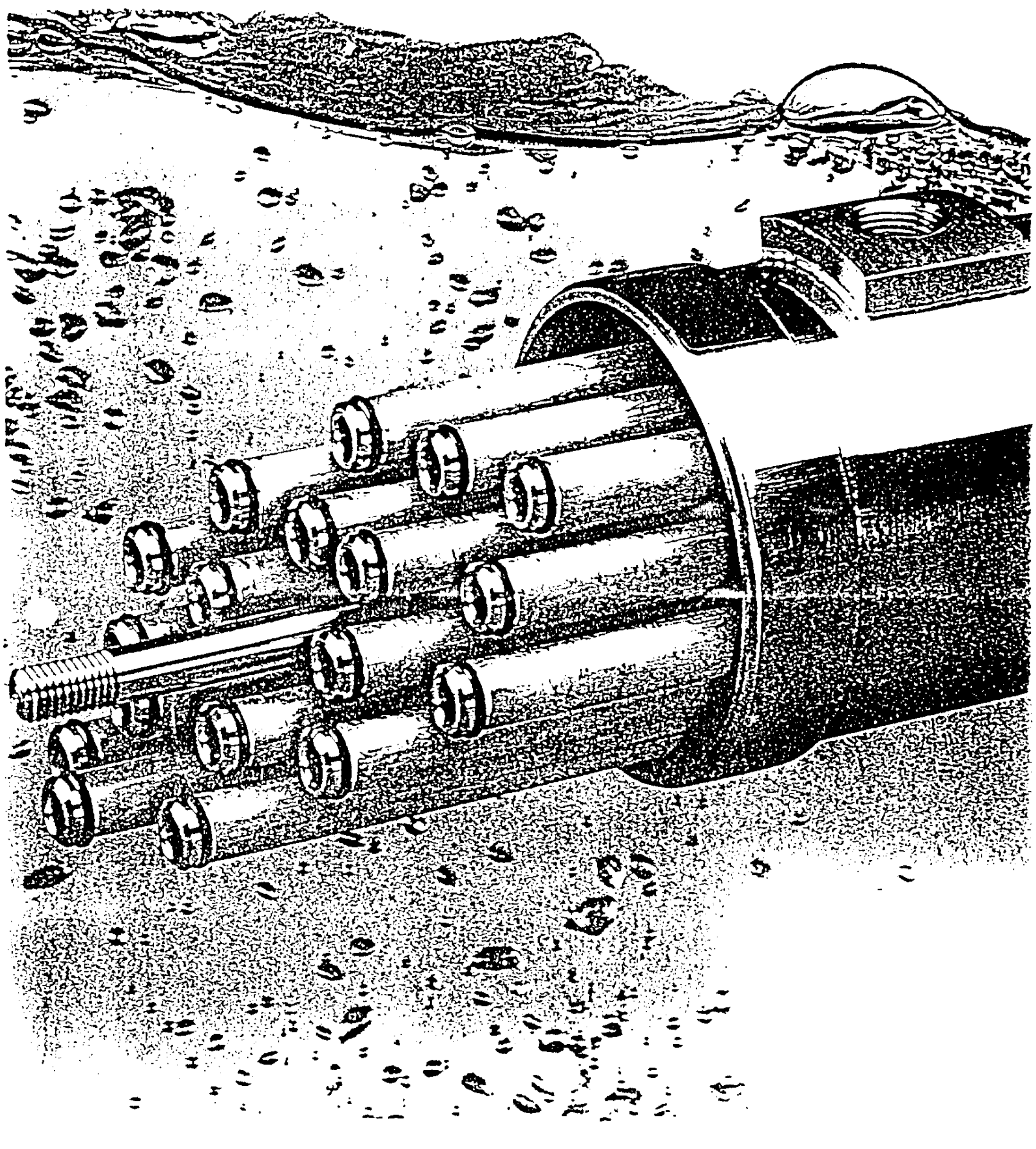
> Tubular

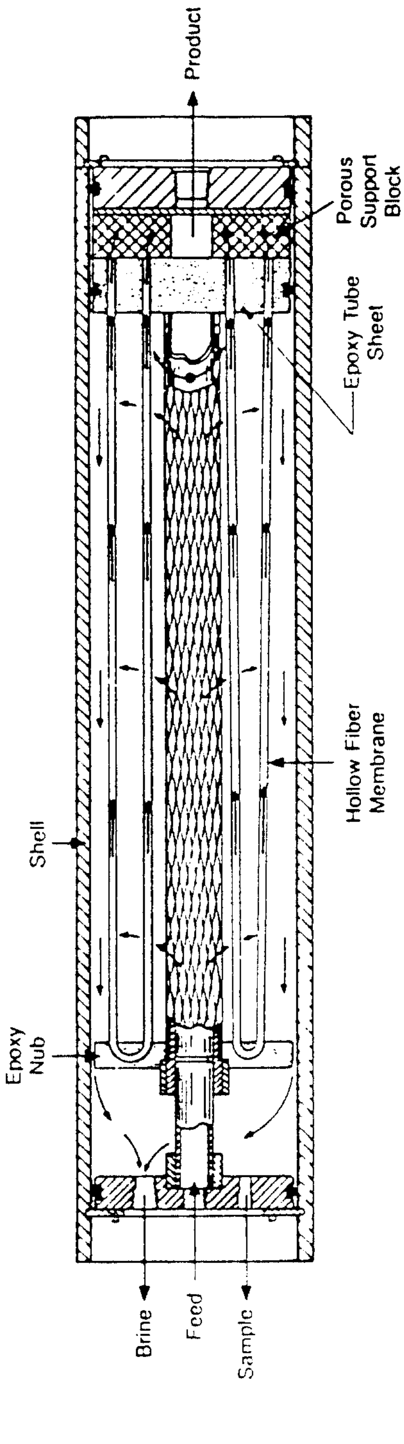
> Hollow Fiber

Internal Flow



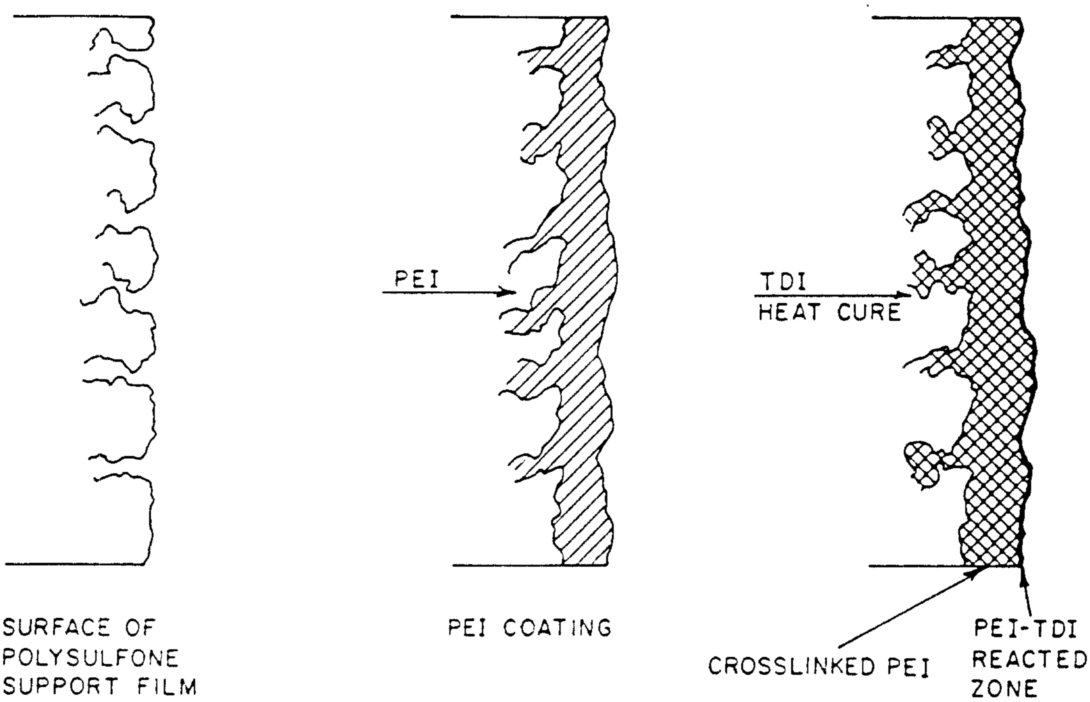

Feed spacer
Central tube
Permeate
Permeate spacer
Membrane




Product
Porous Support Block
Epoxy Tube Sheet
Hollow Fiber Membrane
Shell
Epoxy Nub
Brine
Feed
Sample

Development of Composite Membrane

> In-situ Polymerization



Improvement in the Separation of Organic Solutes

Cellulose acetate membrane with NaCl separation of 96.7 %

Solute		k×10⁴ cm/s	Sepn. %	Solute		k×10⁴ cm/s	Sepn. %
NaF		18.3	98.0	$Sr(NO_3)_2$		17.3	96.4
NaHCOO		18.2	97.7	$Th(NO_3)_4$		11.1	99.9
$NaHCO_3$		16.9	98.6	$Zn(NO_3)_2$		16.5	96.3
NaH phthalate		17.9	97.3	$ZnSO_4$	*	13.0	>99.9
NaH_2PO_4		16.3	99.4	Alcohols			
$NaHSO_4$		17.8	99.4				
Na hydroxy-benzoate		15.0	98.9	Methanol		22.6	9.4
NaI		20.0	95.2	Ethanol		18.7	18.2
$NaIO_3$		16.4	99.0	1-Propanol		16.5	29.3
$Na_3Fe(CN)_6$	*	16.3	>99.9	2-Propanol		16.5	48.0
$Na_4Fe(CN)_6$	*	16.0	>99.9	1-Butanol		15.0	21.8
Na isobutyrate		15.4	99.3	2-Butanol		15.0	49.7
Na m-nitrobenzoate		15.0	99.2	2-Methyl-1-propanol		15.0	49.7
Na o-nitrobenzoate		15.0	99.6	2-Methyl-2-propanol		15.0	86.8
Na p-nitrobenzoate		15.0	99.2	1-Pentanol		13.9	18.5
$NaNO_2$		18.5	94.4	2-Pentanol		13.9	51.7
$NaNO_3$		19.6	93.5	3-Pentanol		13.9	51.7
NaOH		15.1	99.4	2-Methyl-1-butanol		13.9	51.7
Na phenylacetate		14.6	98.9	3-Methyl-1-butanol		13.9	51.7
Na 4-phenylbutyrate		13.2	99.1	2,2-Dimethyl-1-propanol		13.9	75.7
Na β-phenyl-propionate		13.5	99.1	1-Hexanol		13.0	15.5
Na pivalate		14.9	99.7	2-Hexanol		13.0	29.2
Na propionate		15.5	99.3	3-Hexanol		13.0	29.2
Na_2SO_3		16.6	99.8	2-Methyl-1-pentanol		13.0	29.2
Na_2SO_4		16.7	99.8	3-Methyl-1-pentanol		13.0	29.2
$Na_2S_2O_3$		17.1	>99.9	4-Methyl-1-pentanol		13.0	29.2
Na toluate		12.0	98.8	3-Methyl-2-pentanol		13.0	53.1
Na valerate		15.2	99.3	2-Methyl-3-pentanol		13.0	53.1

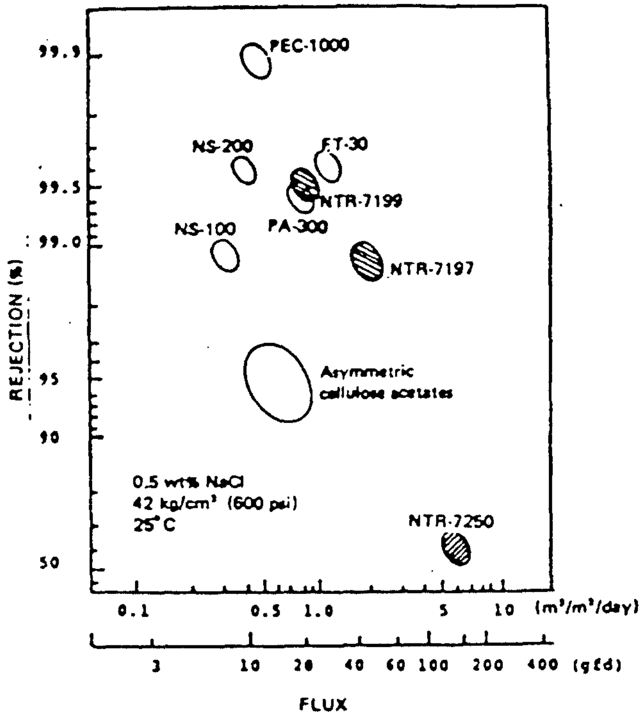
Table 33. Reverse Osmosis Separation Characteristics of PEC-1000 Membranes at 800 psig and 25 °C[291]

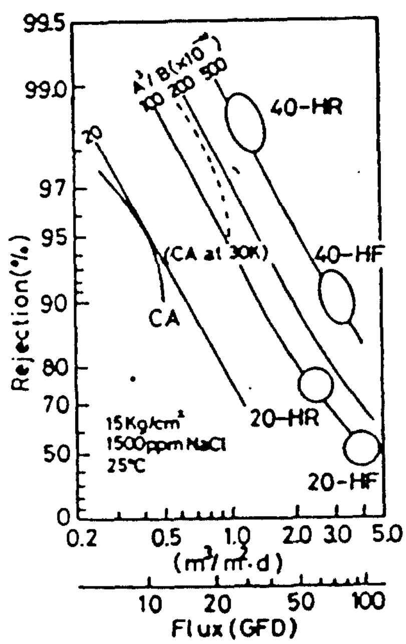
Solute	Solute concn. in feed, wt-%	pH	Solute rejection, %	Water flux, m^3/m^2 day
Methyl alcohol	5	6.9	41	0.38
Ethyl alcohol	5	5.0	92	0.30
Isopropyl alcohol	5	6.5	99.5	0.32
n-Butyl alcohol	5	5.6	99	0.30
Benzyl alcohol	4	7.0	82	0.10
Ethylene glycol	5	6.8	94	0.36
Propylene glycol	5	5.8	99.7	0.40
Glycerine	5	5.8	99.9	0.43
Phenol	1	5.2	99.0	0.24
Formic acid	5	1.9	34	0.52
Acetic acid	5	2.6	91	0.37
Propionic acid	5	2.7	97	0.39
Oxalic acid	0.5	1.8	99.1	0.69
Formaldehyde	5	3.6	69	0.30
Acetaldehyde	3	3.6	89	0.46
Acetone	4	6.7	97	0.29
Methyl ethyl ketone	4	6.6	98	0.21
Ethyl acetate	4	6.8	99.2	0.18
n-Butyl acetate	1	6.9	99.6	0.38
Tetrahydrofuran	5	6.7	99.8	0.28
1,4-Dioxane	5	6.6	99.9	0.40
Ethyldiamine	5	12.1	99.5	0.08
Aniline	1	8.3	95	0.11
Urea	1	6.9	85	0.56
N,N-Dimethylformamide	5	6.5	98	0.32
N,N-Dimethylacetamide	5	6.5	99.6	0.30
ε-Caprolactam	5	5.8	99.9	0.30
Dimethylsulfoxide	5	6.4	99.6	0.34
Lactose	5	6.1	>99.9	0.50

Table 32. Reverse Osmosis Separation Characteristics of PA-300 Membranes at 1000 psig and 25°C[290]

Solute	Solute conc., ppm	pH	Solute rejection, %
Sodium nitrate	10,000	6.0	99.0
Ammonium nitrate	9,600	5.7	98.1
Boric acid	280	4.8	65 - 70
Urea	1,250	4.9	80 - 85
Phenol	100	4.9	93
Phenol	100	12.0	> 99
Ethyl alcohol	700	4.7	90
Glycerine	1,400	5.6	99.7
DL-aspartic acid	1,500	3.2	98.3
Ethyl acetate	366	6.0	95.3
Methyl ethyl ketone	465	5.2	94
Acetic acid	190	3.8	65-70
Acetonitrile	425	6.3	> 25
Acetaldehyde	660	5.8	70-75
Dimethyl phthalate	37	6.2	> 95
2,4-Dichlorophenoxy acetic acid	130	3.3	> 98.5
Citric acid	10,000	2.6	99.9
Alcozyme (soap)	2,000	9.3	99.3
o-Phenyl phenol	110	6.5	> 99
Tetrachloroethylene	104	5.9	> 93
Sodium silicate	42	8.6	> 96
Sodium chromate	1,200	7.8	> 99
Chromic acid	870	3.9	90-95
Cupric chloride	1,000	5.0	99.2
Zinc chloride	1,000	5.2	99.3
Trichlorobenzene	100	6.2	> 99
Butyl benzoate	200	5.8	99.3

Improvement in Reverse Osmosis Membrane Flux





Membrane Gas Separation

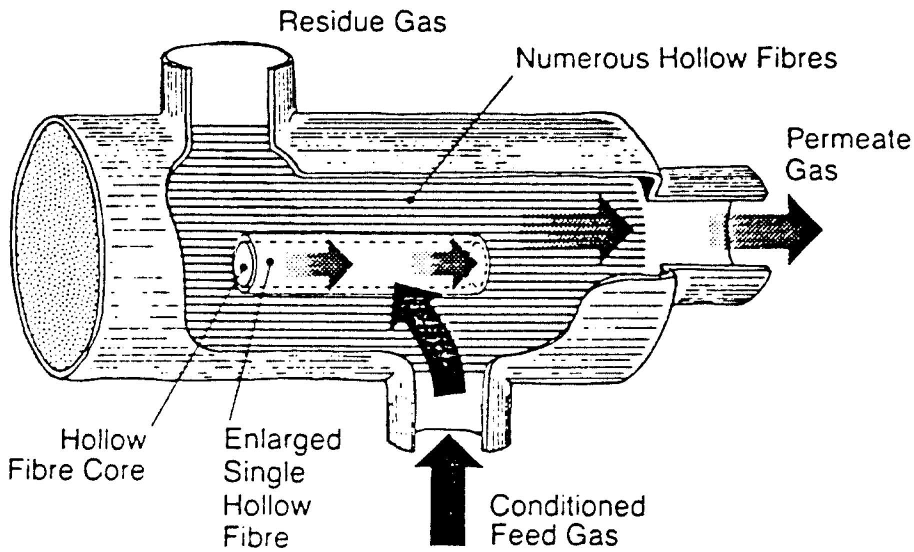
> **Dry Asymmetric Membranes**

Hollow Fiber, Spiral Wound
Cellulose Acetate, Polyamide, Polyimide

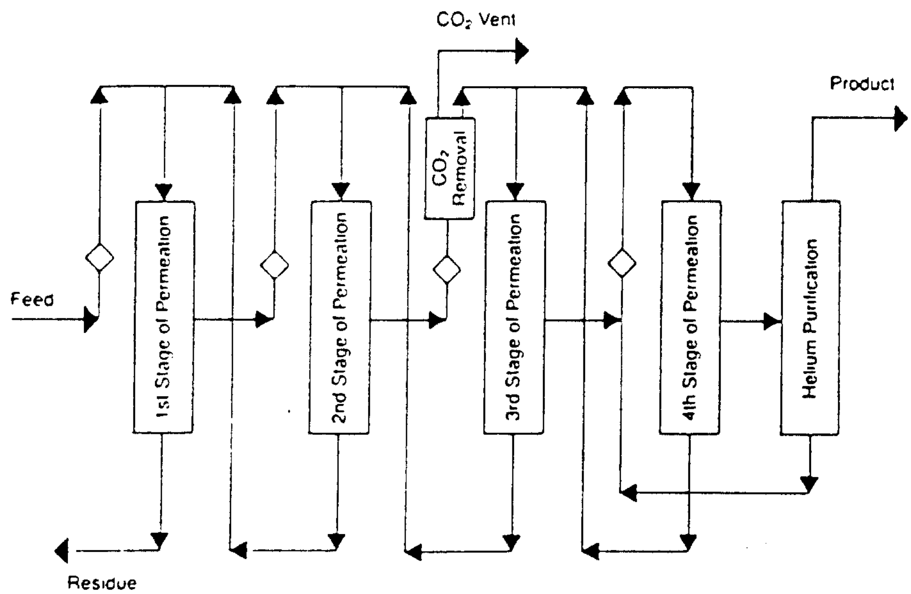
> **Composite Membranes**

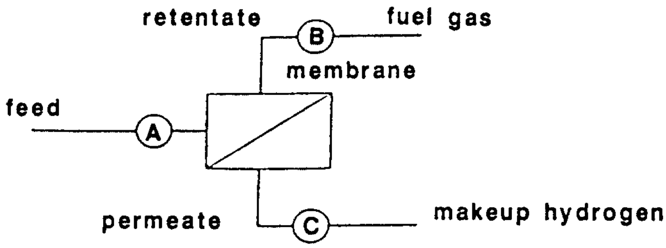
PRISM Membrane, PRISM Alpha Membrane

Resistance Theory



(Source: International Permeation Inc. 1986)

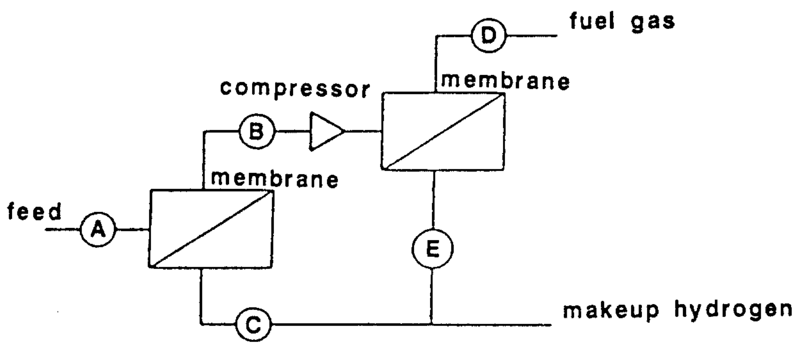




	A	B	C
Composition (mole %)			
H_2	71.0 (55.0)	26.3 (41.7)	98.0 (98.0)
CH_4	16.0 (18.9)	40.3 (24.4)	1.3 (1.1)
C_2^+	13.0 (26.1)	33.4 (33.9)	0.7 (0.9)
Flow rate (Nm^3/day)	1000 (1000)	377 (764)	623 (236)
Pressure (bar)	30.0	30.0	5.0

H_2 recovery: 86.0% (42.1%)
α (H_2/CH_4) = 60

* figures in brackets illustrate the effect of lower feed purity

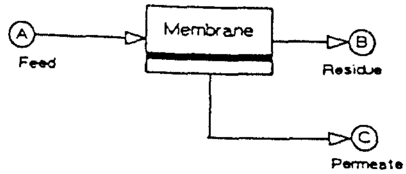


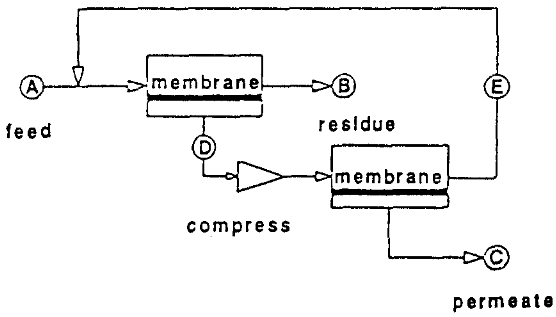
	A	B	C	D	E
Composition (mole %)					
H_2	55.0	41.7	98.0	18.8	96.0
CH_4	18.9	24.4	1.1	33.7	2.2
C_2^+	26.1	33.9	0.9	47.5	1.8
Flow rate (Nm^3/day)	1000	764	236	538	226
Pressure (bar)	30.0	30.0	5.0	60.0	5.0

H_2 recovery: 81.5%

	A	B	C
Composition (mole%)			
CH_4	93.0	98.0	63.4
CO_2	7.0	2.0	36.6
Flow rate (MM_{SCFD})	20.00	17.11	2.89
Pressure (psig)	850	835	10

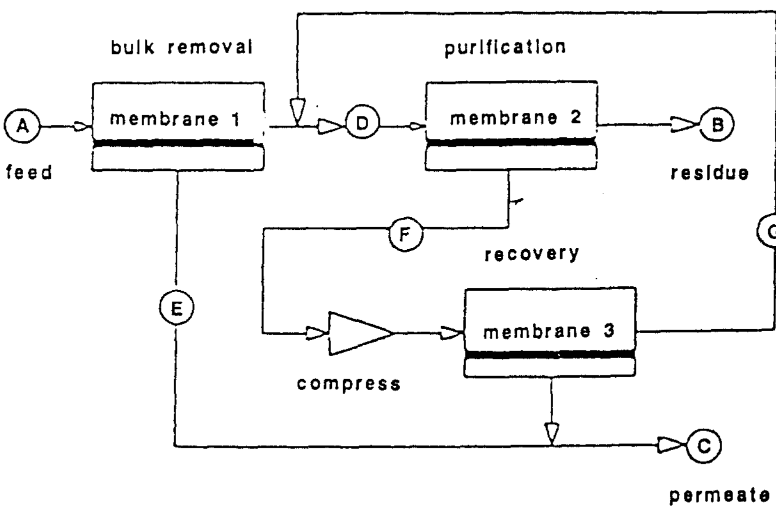
Methane Recovery = 92%





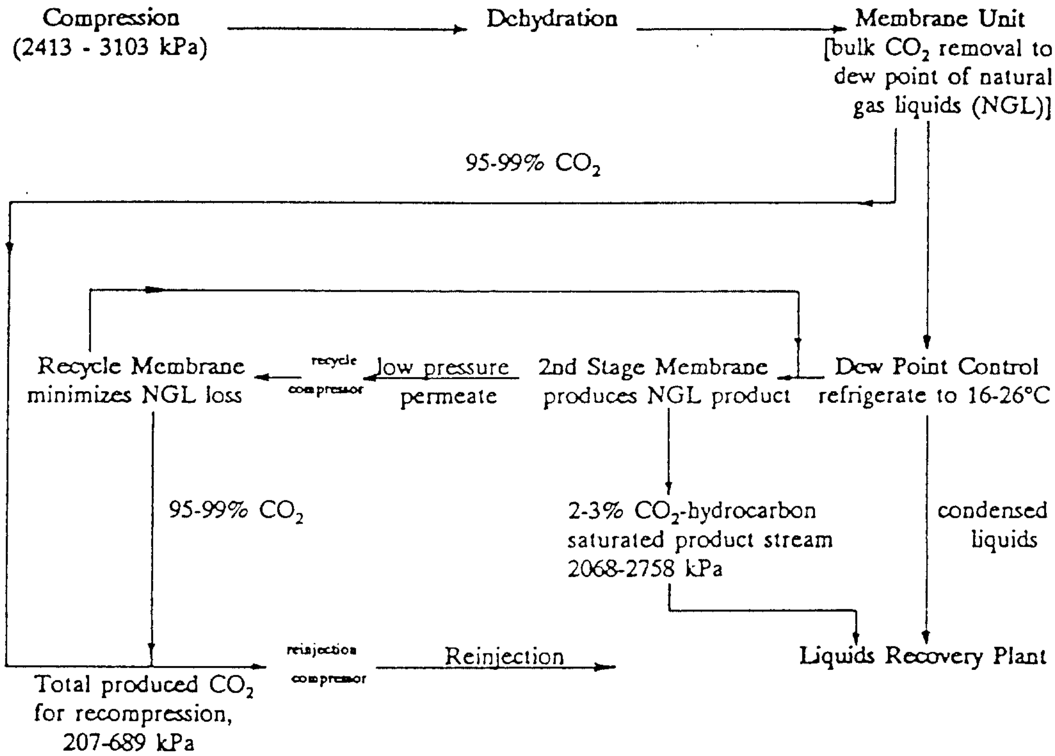
	A	B	C	D	E
Composition (mole %)					
CH_4	93.0	98.0	18.9	63.4	93.0
CO_2	7.0	2.0	81.1	36.6	7.0
Flow Rate (MM_{SCFD})	20.00	18.74	1.26	3.16	1.90
Pressure (psig)	850	835	10	10	850

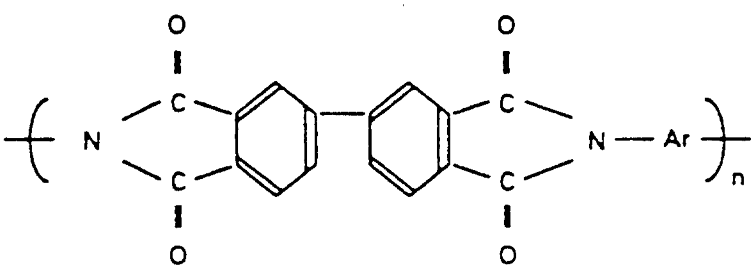
Methane Recovery = 98.7%



	A	B	C	D	E	F	G
Composition (mole%)							
CH_4	93.0	98.0	49.2	96.1	56.1	72.1	93.0
CO_2	7.0	2.0	50.8	3.9	43.9	27.9	7.0
Flow Rate (MM_{SCFD})	20.00	17.95	2.05	19.39	1.62	1.44	1.01
Pressure (psig)	850	835	10	840	10	10	850

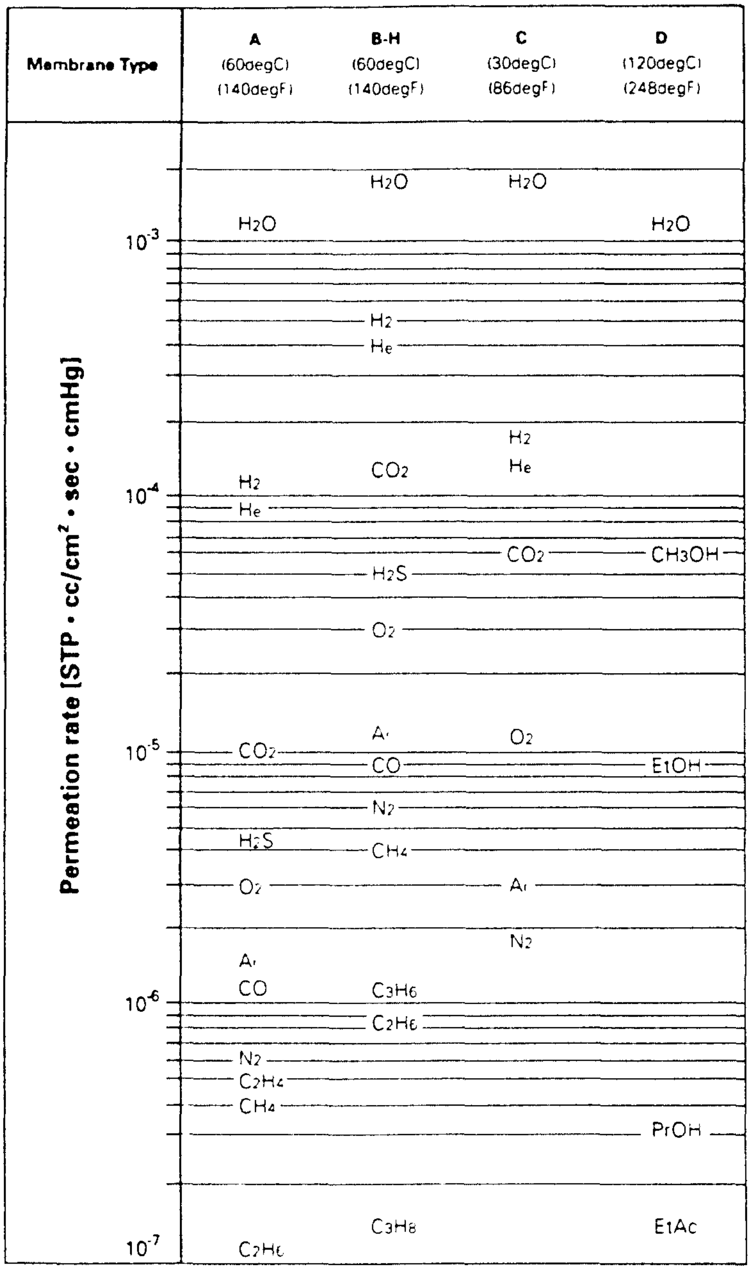
Methane Recovery = 94.6%

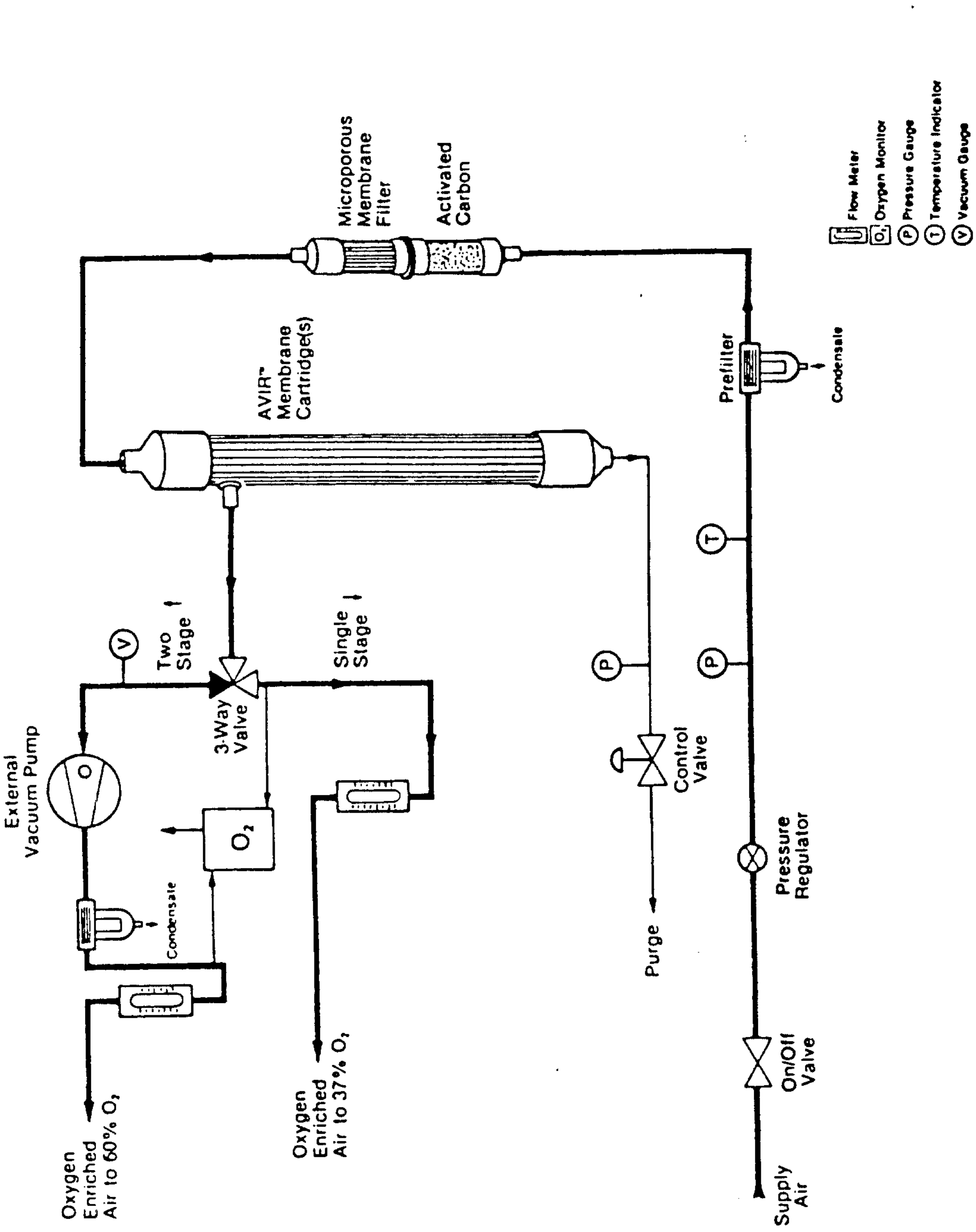

Compression
(2413 - 3103 kPa)
Dehydration
Membrane Unit
[bulk CO_2 removal to
dew point of natural
gas liquids (NGL)]
95-99% CO_2
Recycle Membrane
minimizes NGL loss
recycle
compressor
low pressure
permeate
2nd Stage Membrane
produces NGL product
Dew Point Control
refrigerate to 16-26°C
95-99% CO_2
2-3% CO_2-hydrocarbon
saturated product stream
2068-2758 kPa
condensed
liquids
reinjection
compressor
Reinjection
Liquids Recovery Plant
Total produced CO_2
for recompression,
207-689 kPa



Ar shows divalent aromatic radical

Example permeability data for UBE's polyimide membranes





Microporous Membrane Filter
Activated Carbon
AVIR™ Membrane Cartridge(s)
Prefilter
Condensate
External Vacuum Pump
Two Stage
Single Stage
3-Way Valve
O_2
Condensate
Purge
Control Valve
Pressure Regulator
On/Off Valve
Supply Air
Oxygen Enriched Air to 60% O_2
Oxygen Enriched Air to 37% O_2
Flow Meter
O_2 Oxygen Monitor
P Pressure Gauge
T Temperature Indicator
V Vacuum Gauge

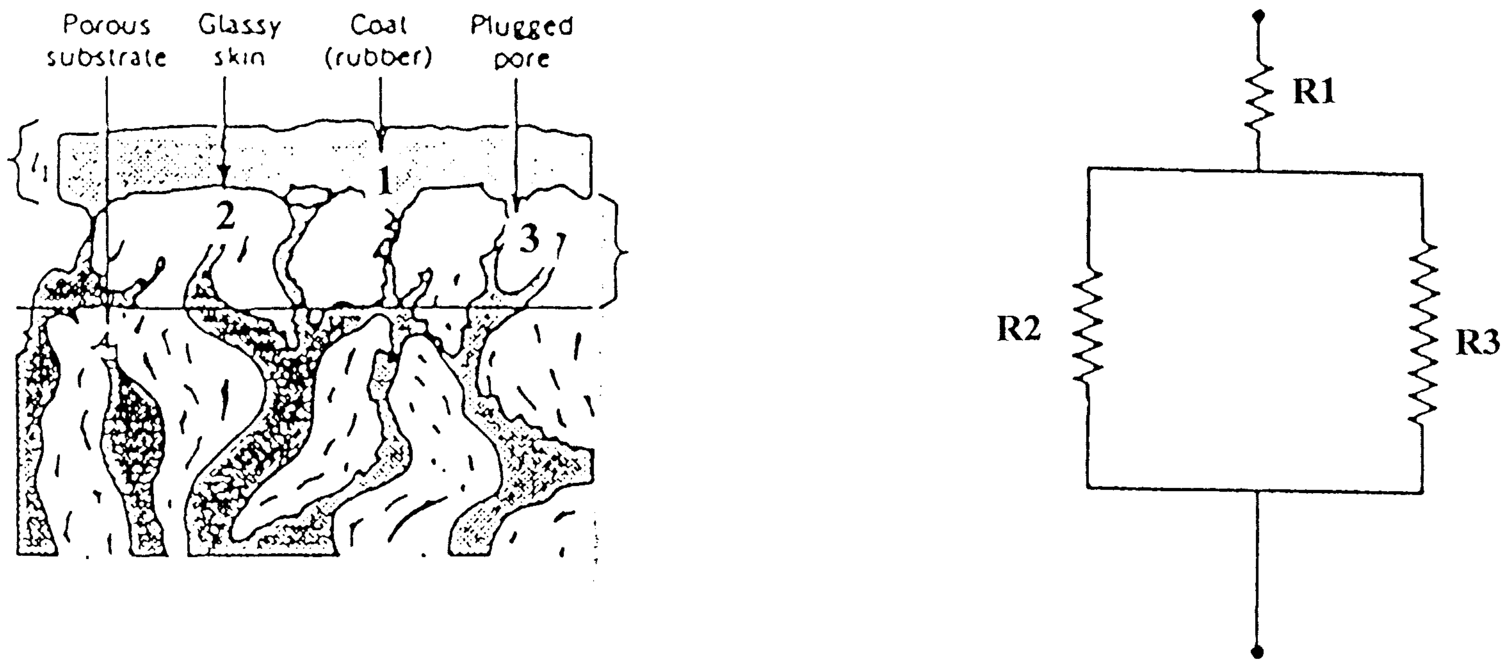
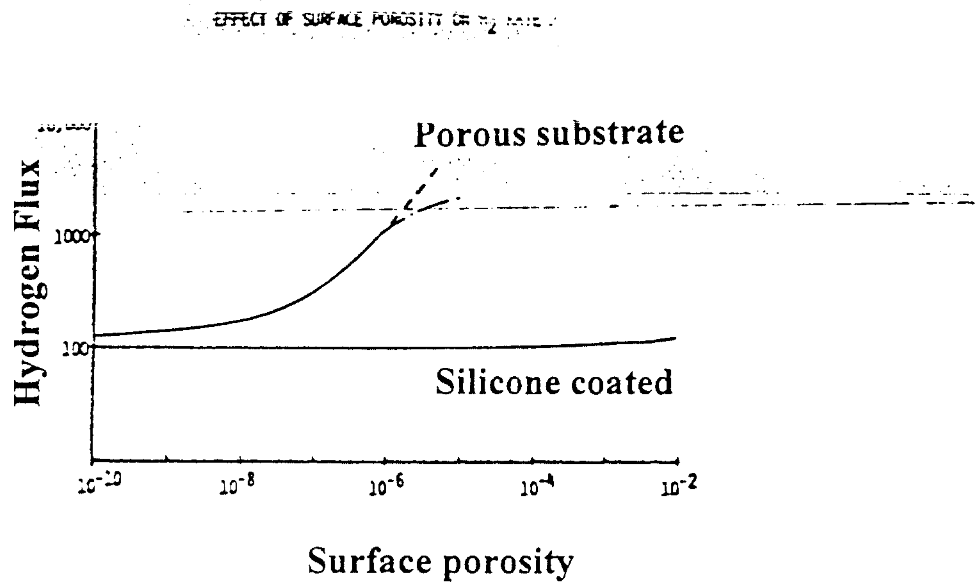
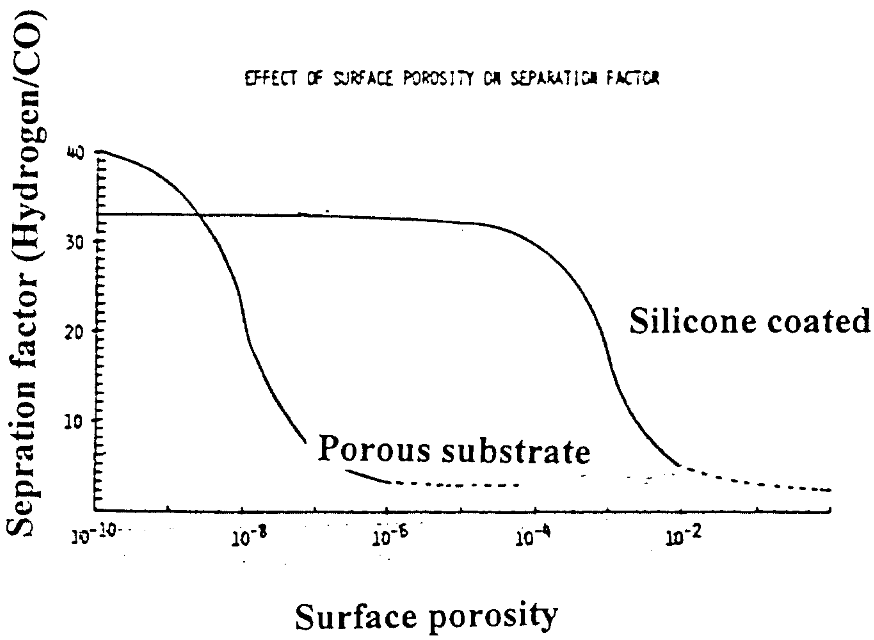
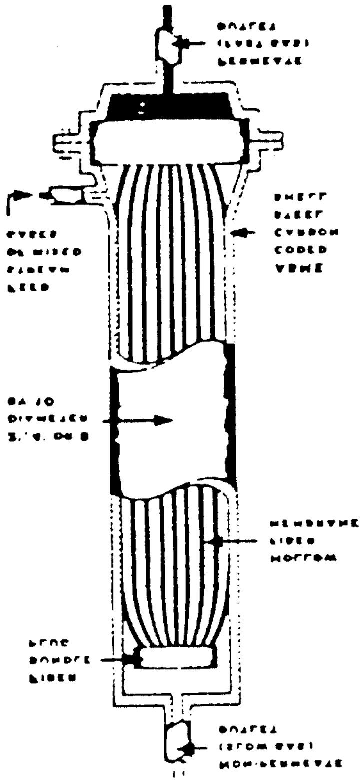
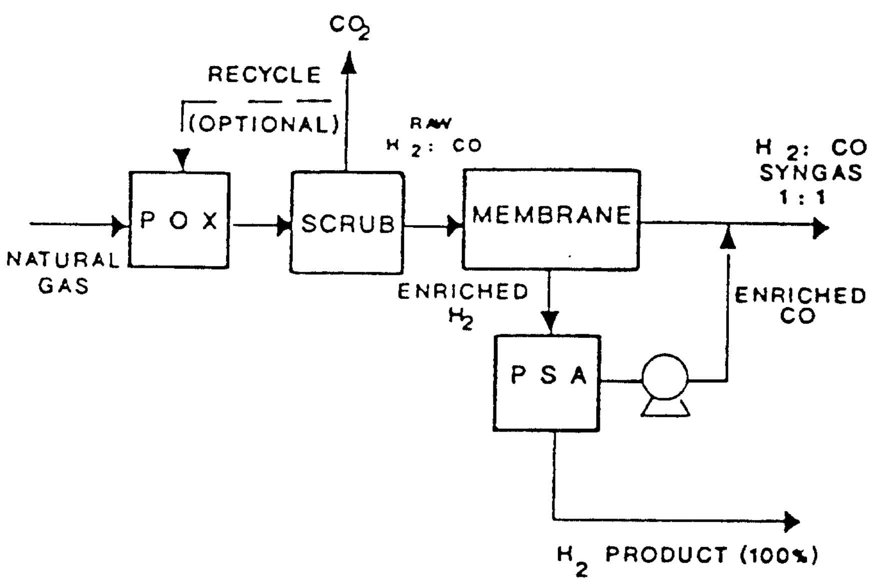


Figure 3: Coated membrane and electric circuit analog.


EFFECT OF SURFACE POROSITY
Porous substrate
Hydrogen Flux
1000
100
Silicone coated
10^-10
10^-8
10^-6
10^-4
10^-2
Surface porosity


Sepration factor (Hydrogen/CO)
EFFECT OF SURFACE POROSITY ON SEPARATION FACTOR
40
30
20
10
Silicone coated
Porous substrate
10^-10
10^-8
10^-6
10^-4
10^-2
Surface porosity




CO2
RECYCLE
(OPTIONAL)
RAW
H 2: CO
H 2: CO
SYNGAS
1 : 1
P O X
SCRUB
MEMBRANE
NATURAL
GAS
ENRICHED
H2
ENRICHED
CO
P S A
H2 PRODUCT (100%)

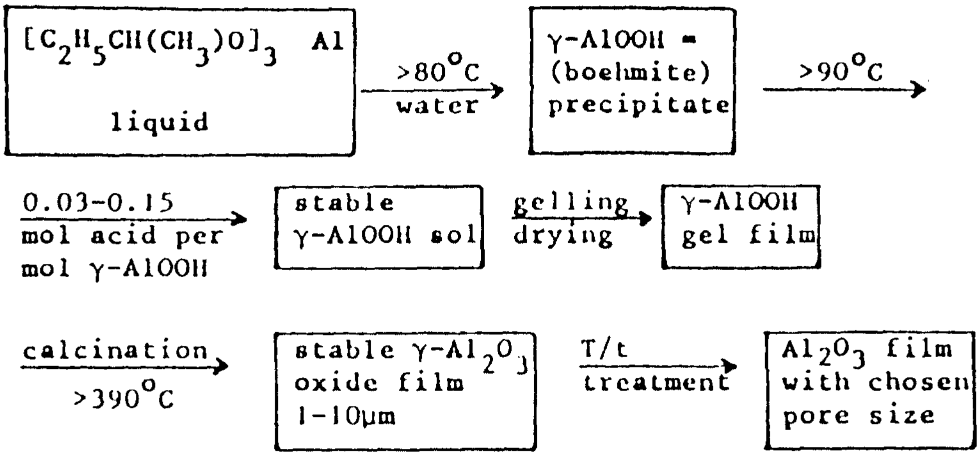
Development of Inorganic Membranes

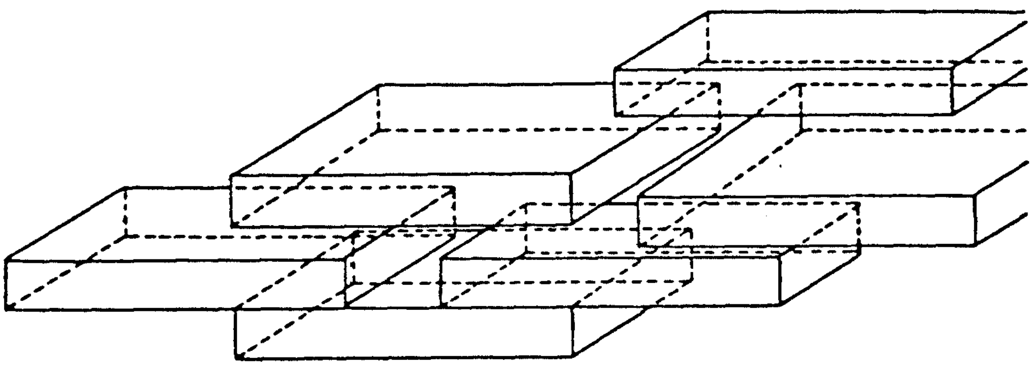
> Alumina Membrane

Sol-Gel Method

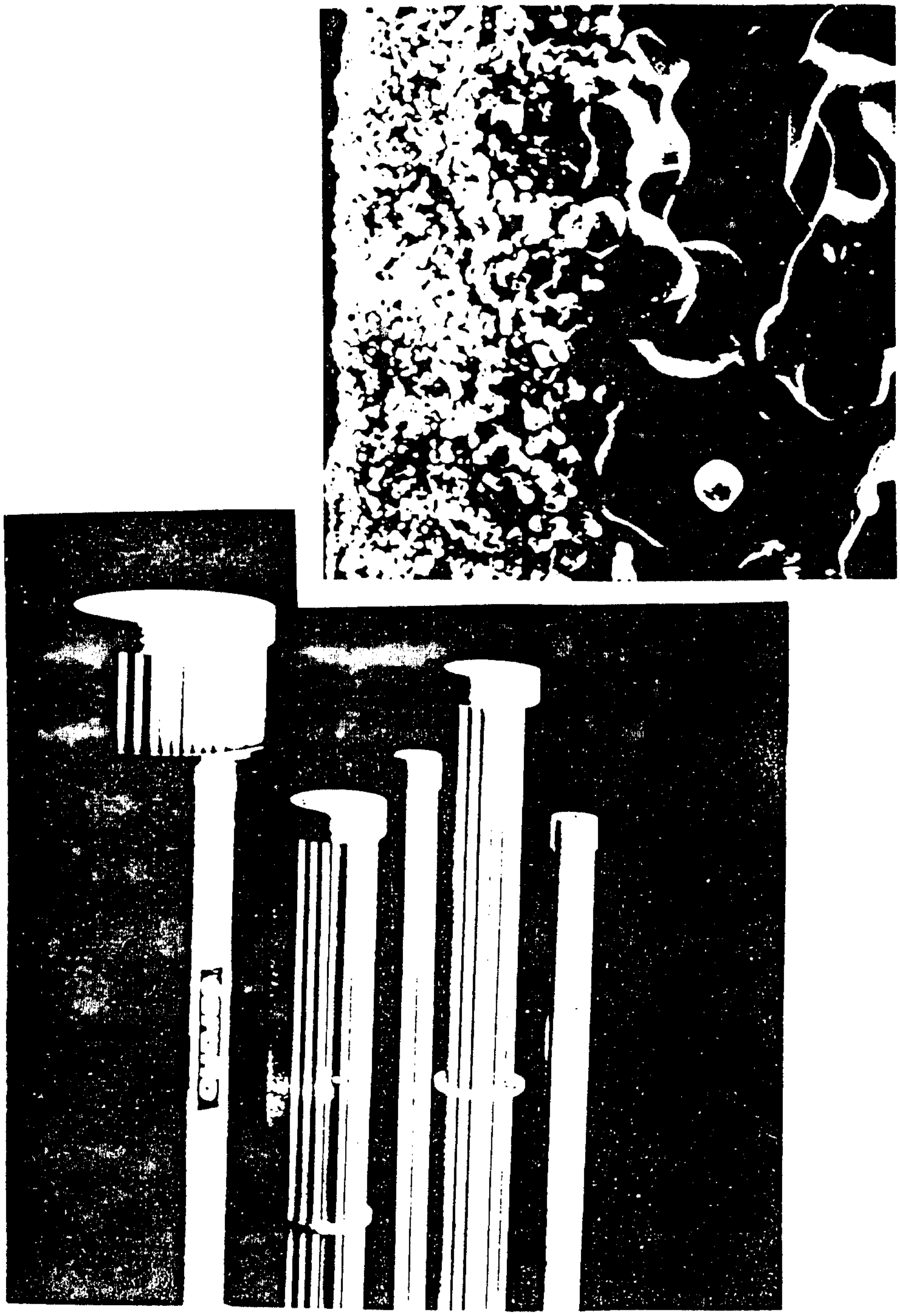
> Porous Carbon Membrane

> Zeolite Membrane





Model of boehmite membrane microstructure

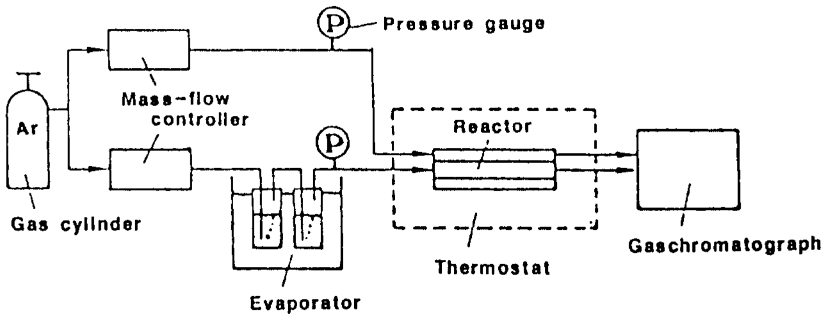


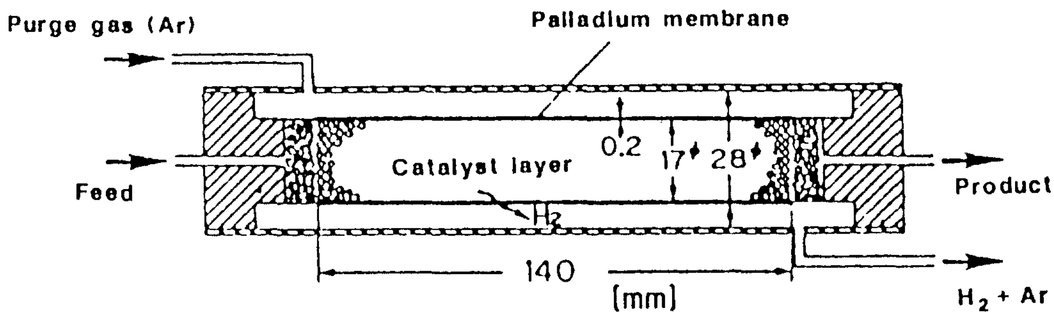
5. Asymmetric structure of Ceraflo membrane (a), and tube assembly (b) (13).

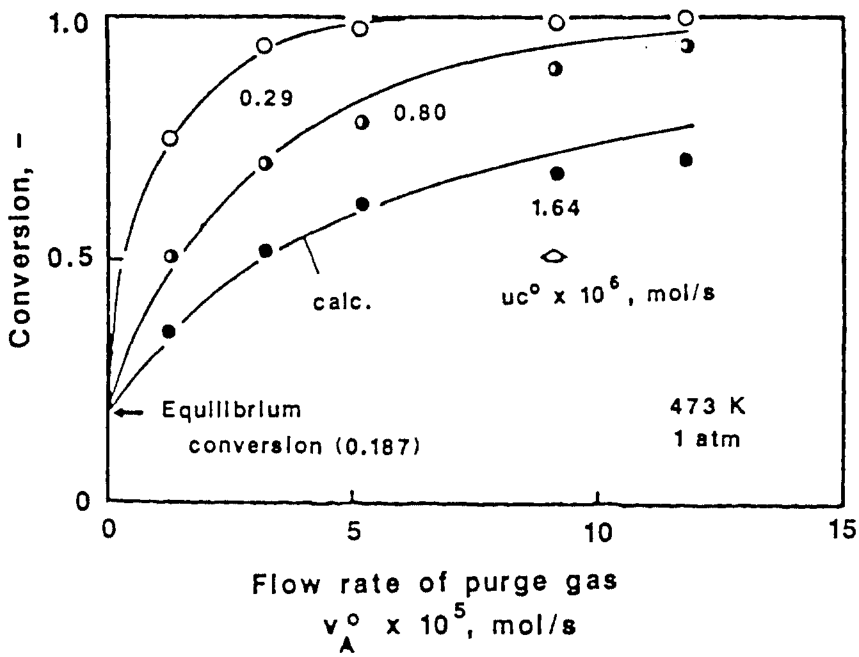
4. Surface retention of particles by Anotech ANOPORE Membrane.

Membrane Reactor

> Shift in Equilibrium



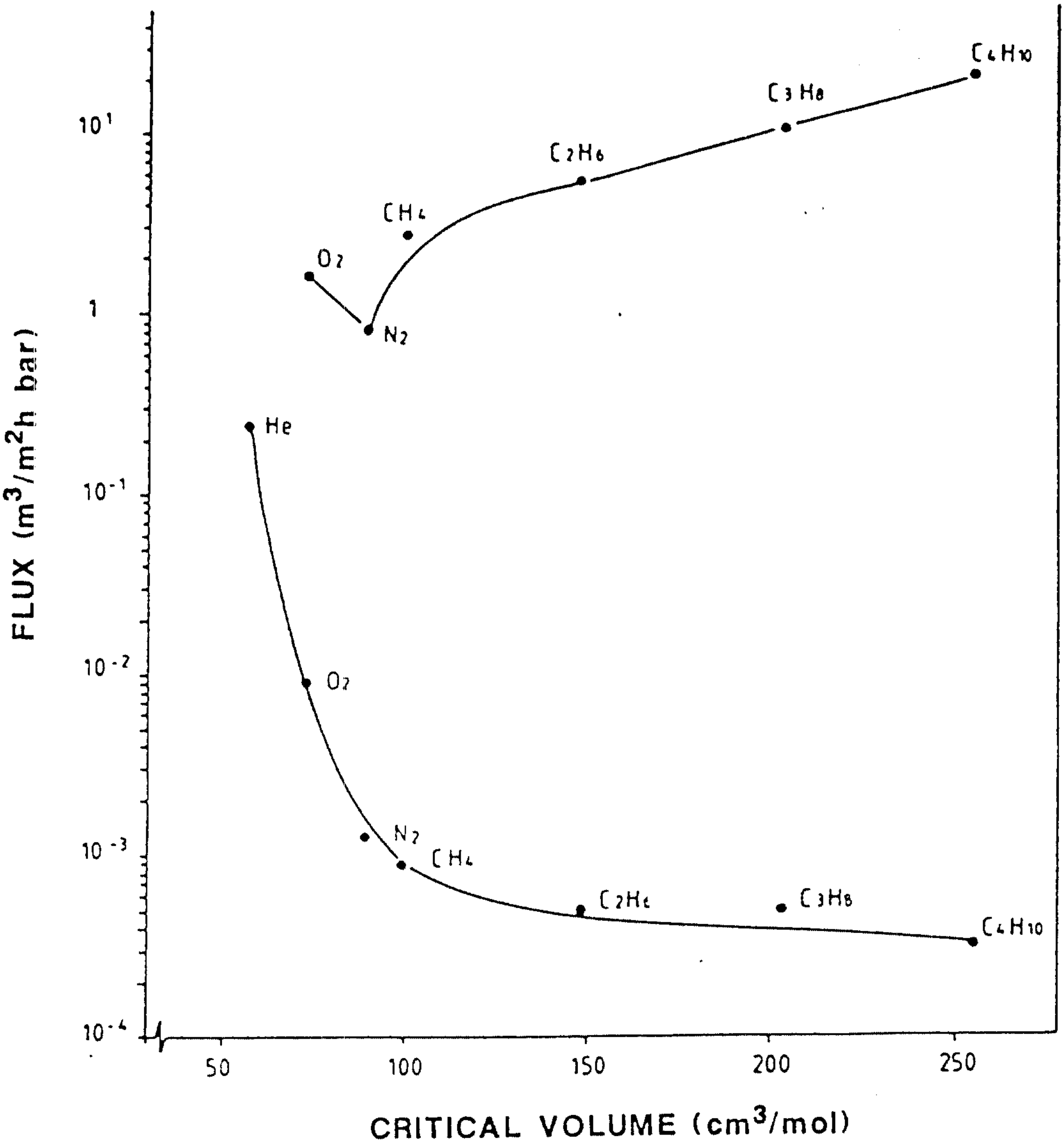

Purge gas (Ar)
Palladium membrane
Feed
Catalyst layer
0.2
17ϕ
28ϕ
H_2
Product
140
[mm]
H_2 + Ar

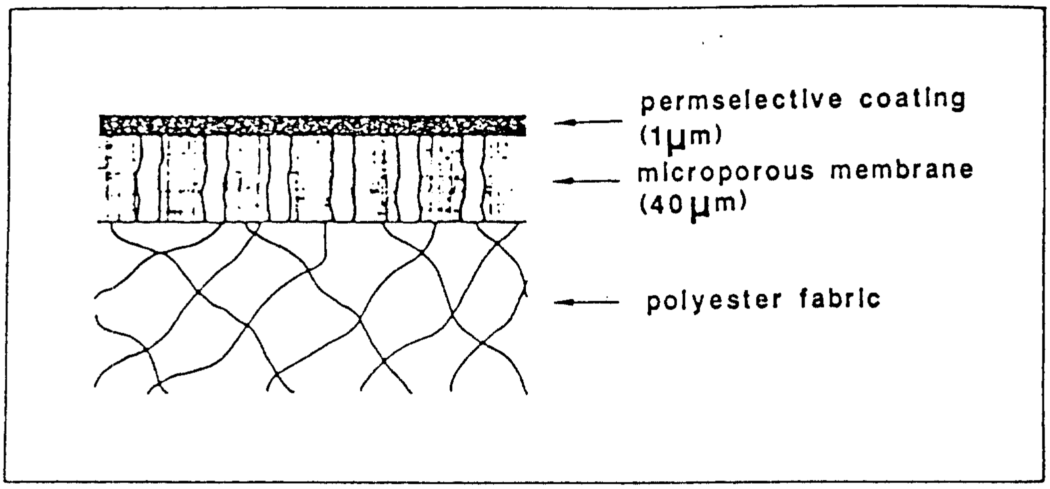

1.0
0.5
0
Conversion, -
0.29
0.80
1.64
calc.
uc° x 10⁶, mol/s
Equilibrium
conversion (0.187)
473 K
1 atm
0
5
10
15
Flow rate of purge gas
v°A x 10⁵, mol/s

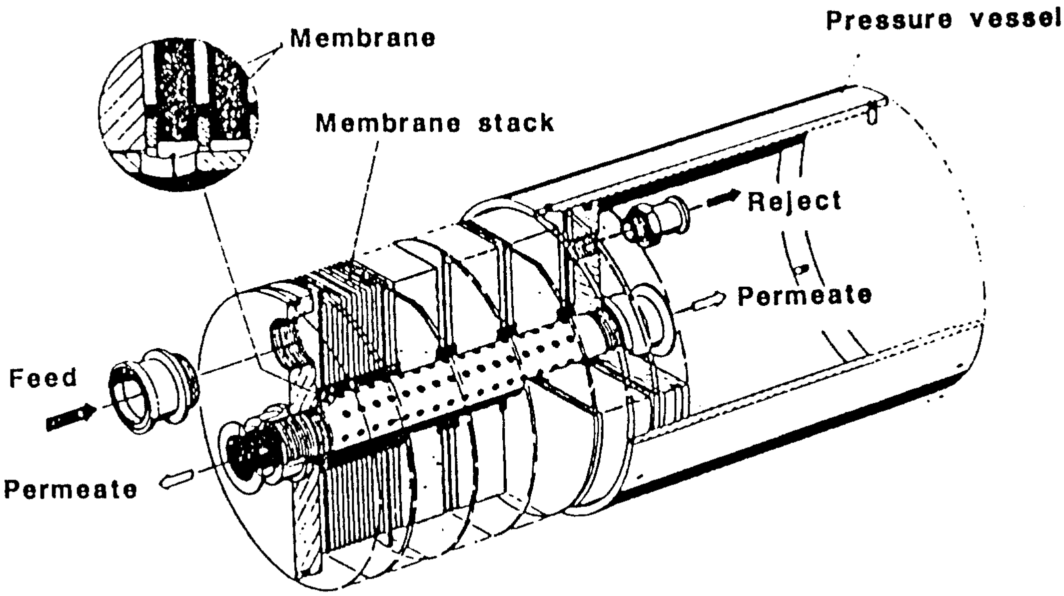
Vapor Permeation

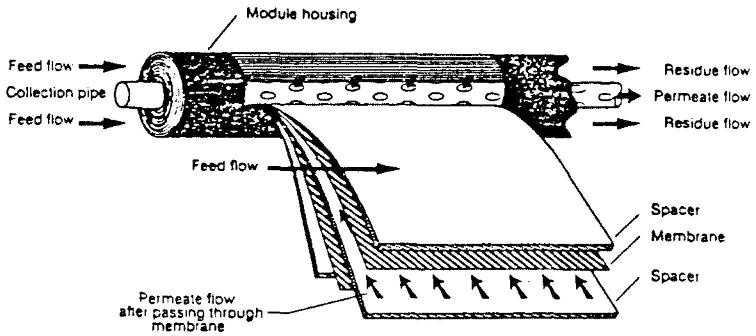
> VOC Removal from Air

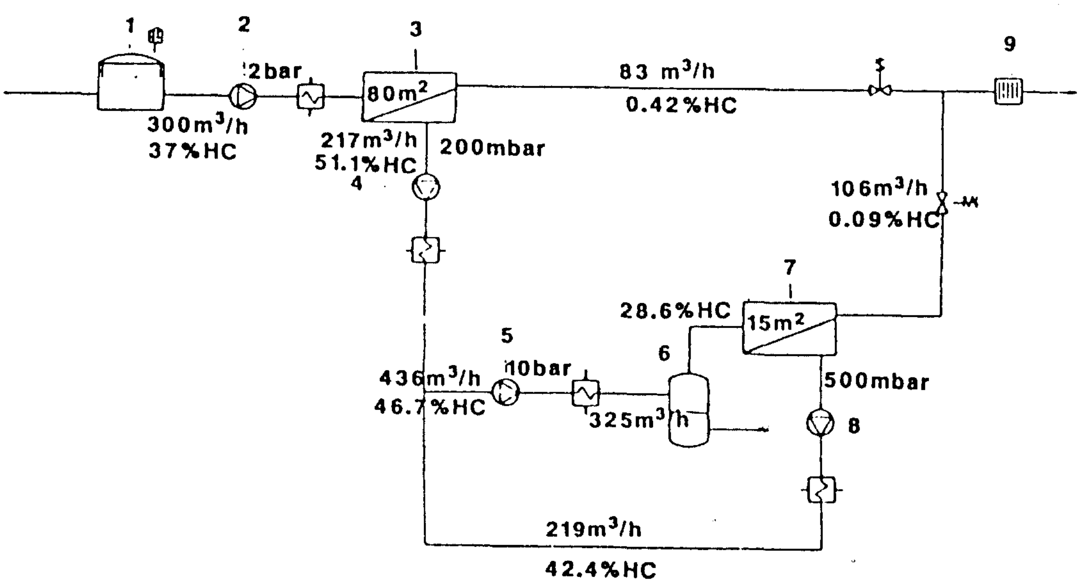
> Dehumidification

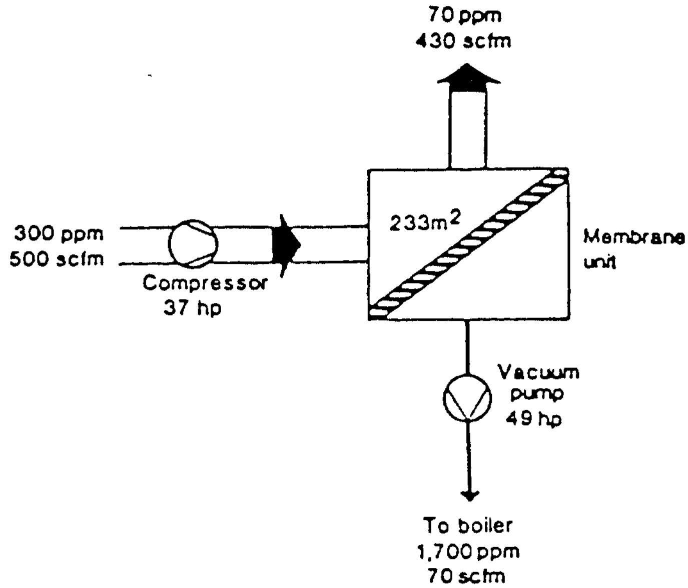

FLUX (m3/m2h bar)
10¹
1
10⁻¹
10⁻²
10⁻³
10⁻⁴
C₄H₁₀
C₃H₈
C₂H₆
CH₄
O₂
N₂
He
50
100
150
200
250
CRITICAL VOLUME (cm³/mol)


permselective coating
(1 μm)
microporous membrane
(40 μm)
polyester fabric


Membrane
Pressure vessel
Membrane stack
Reject
Permeate
Feed
Permeate

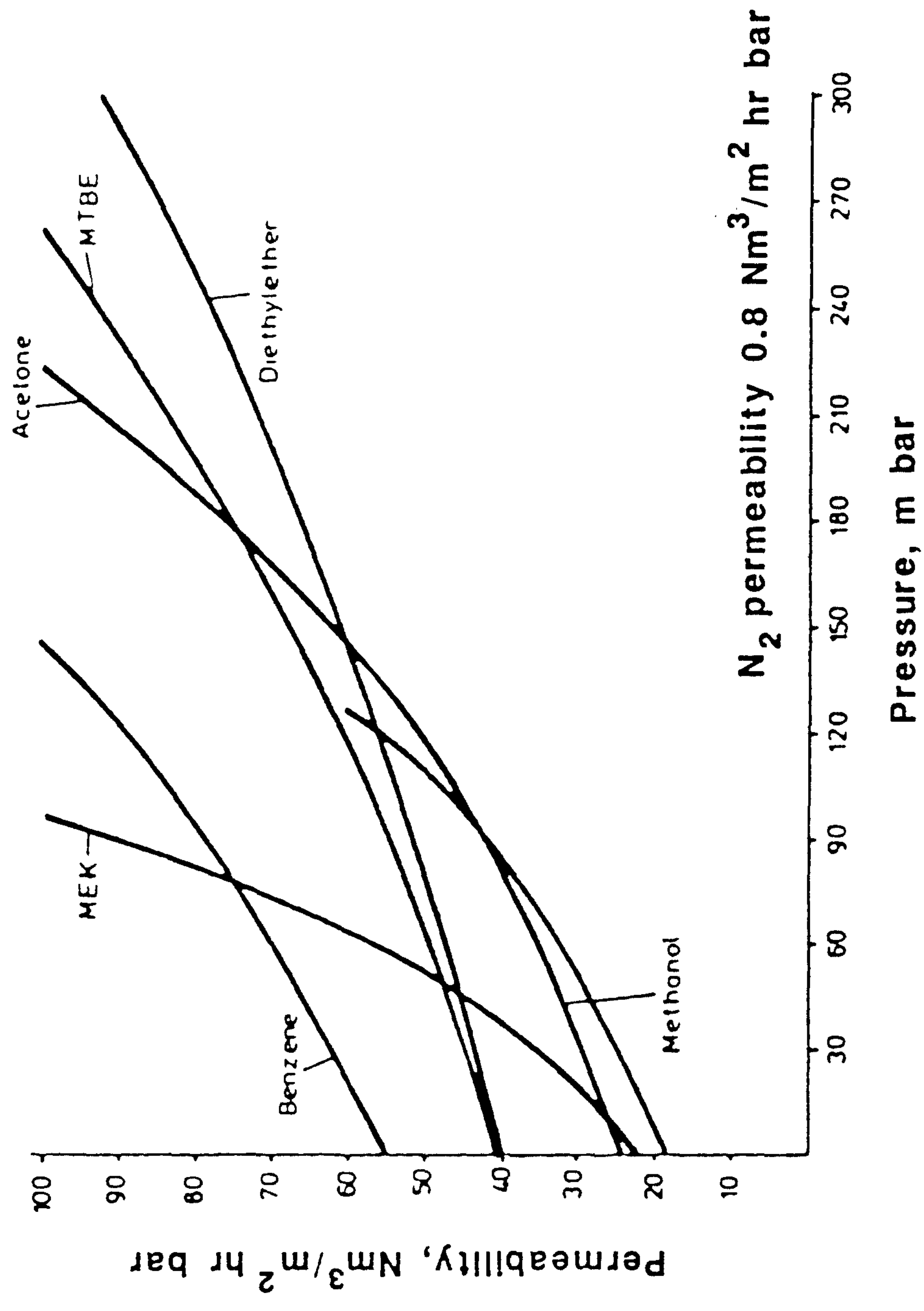

Module housing
Feed flow
Collection pipe
Feed flow
Residue flow
Permeate flow
Residue flow
Feed flow
Spacer
Membrane
Spacer
Permeate flow after passing through membrane


1
2
3
9
2bar
80m²
83 m³/h
0.42%HC
300m³/h
37%HC
217m³/h
51.1%HC
200mbar
4
106m³/h
0.09%HC
7
28.6%HC
15m²
5
6
10bar
436m³/h
46.7%HC
325m³/h
500mbar
8
219m³/h
42.4%HC

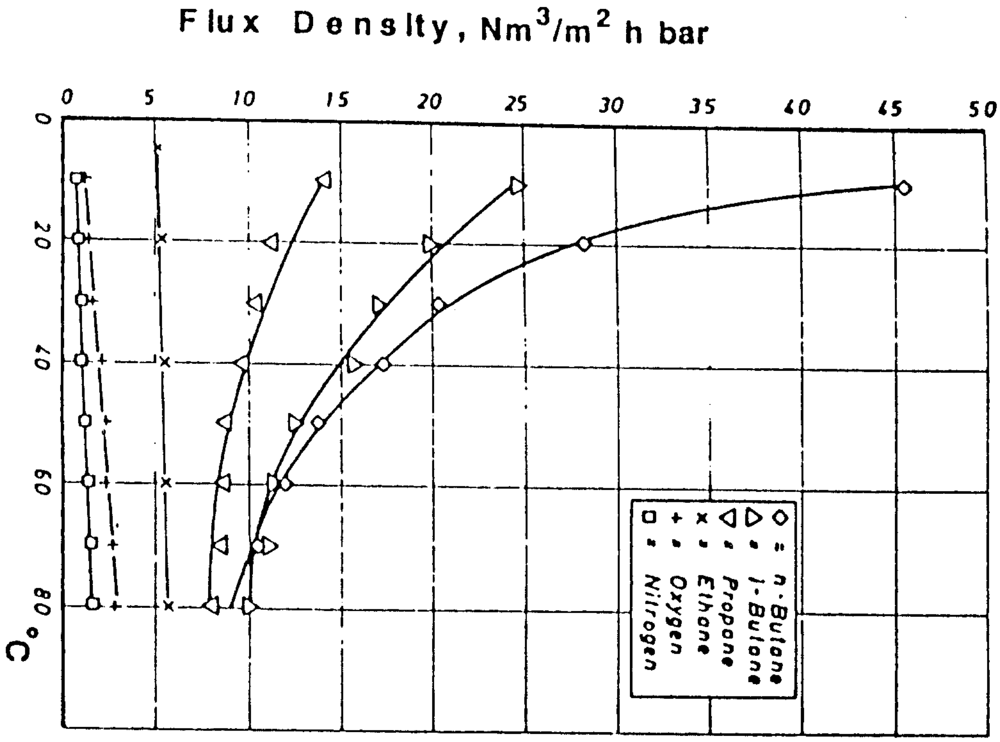


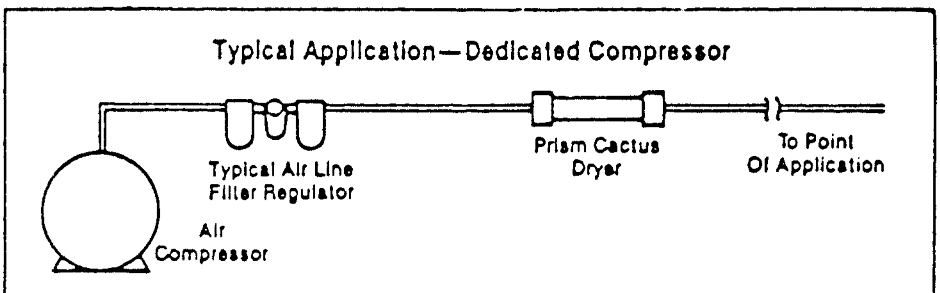
	FEED	PERMEATE	RESIDUE
Flow (scfm)	500	70	430
Concentration (ppm)	300	1,700	70

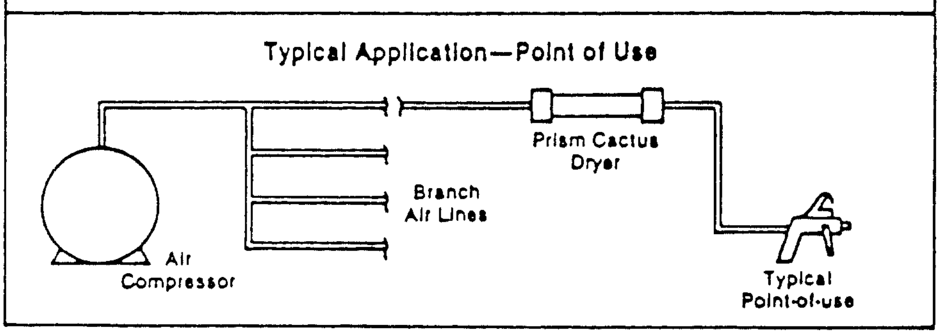
Membrane Selectivity	30
Membrane Area	233 m^2
Vacuum Pumps	49 hp
Compressors	37 hp
CAPITAL COSTS	\$282,000 \$560/scfm feed
OPERATING COSTS	
Depreciation + Interest	\$ 33,200
Miscellaneous	10,400
Module replacement (3-year lifetime)	46,600
Energy	22,800
	\$113,000/yr
OPERATING COST	\$0.52/1000 scf feed 0.68/lb solvent recovered



Permeability, Nm³/m² hr bar
100
90
80
70
60
50
40
30
20
10
30
60
90
120
150
180
210
240
270
300
Pressure, m bar
N₂ permeability 0.8 Nm³/m² hr bar
Benzene
MEK
Acetone
MTBE
Diethylether
Methanol


Flux Density, Nm3/m2 h bar
0 5 10 15 20 25 30 35 40 45 50
0 20 40 60 80
°C
◇ = n-Butane
▷ = i-Butane
◁ = Propane
× = Ethane
+ = Oxygen
□ = Nitrogen


Typical Application—Dedicated Compressor
Typical Air Line
Filter Regulator
Prism Cactus
Dryer
To Point
Of Application
Air
Compressor


Typical Application—Point of Use
Prism Cactus
Dryer
Branch
Air Lines
Air
Compressor
Typical
Point-of-use

Pervaporation

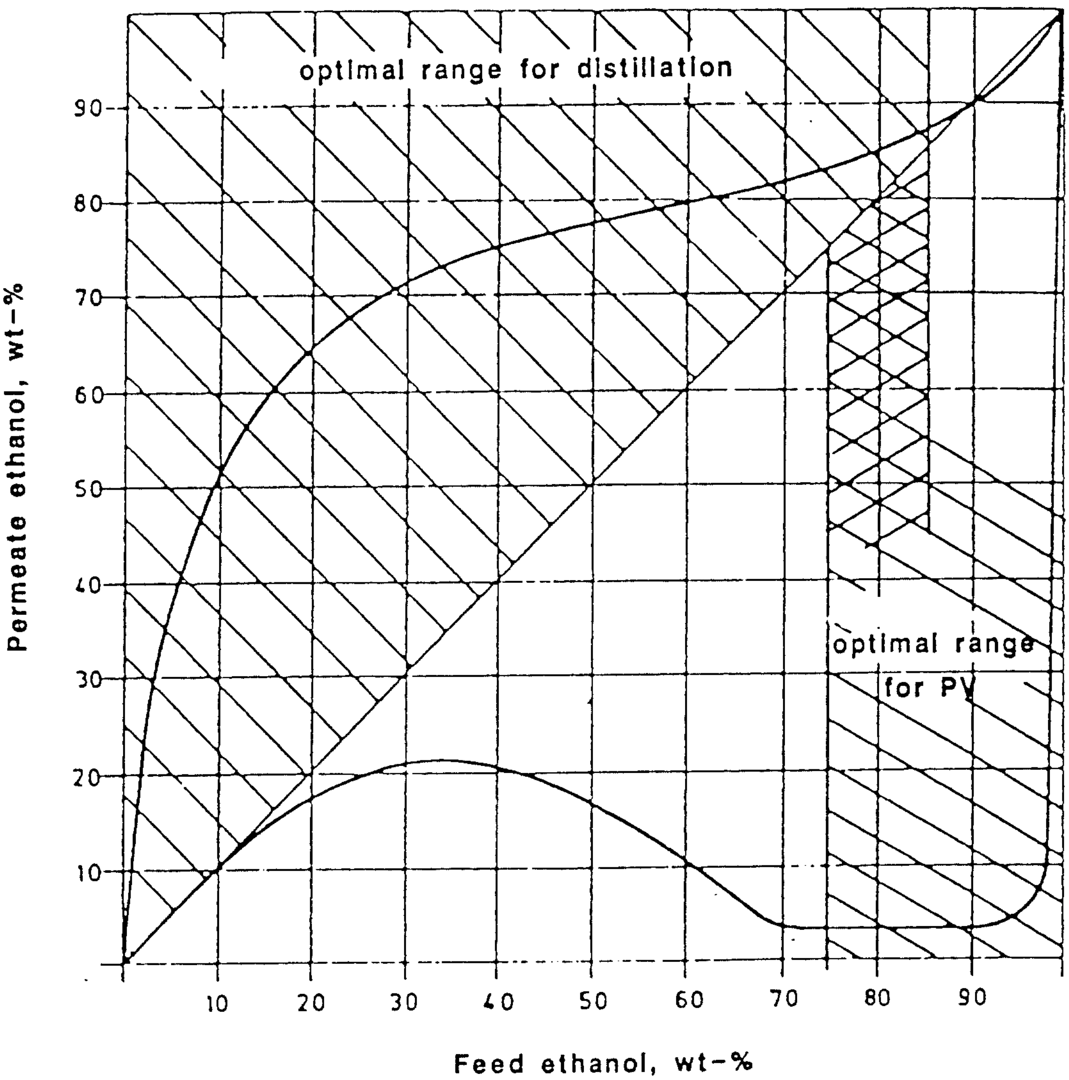
> Dehydration of Ethanol

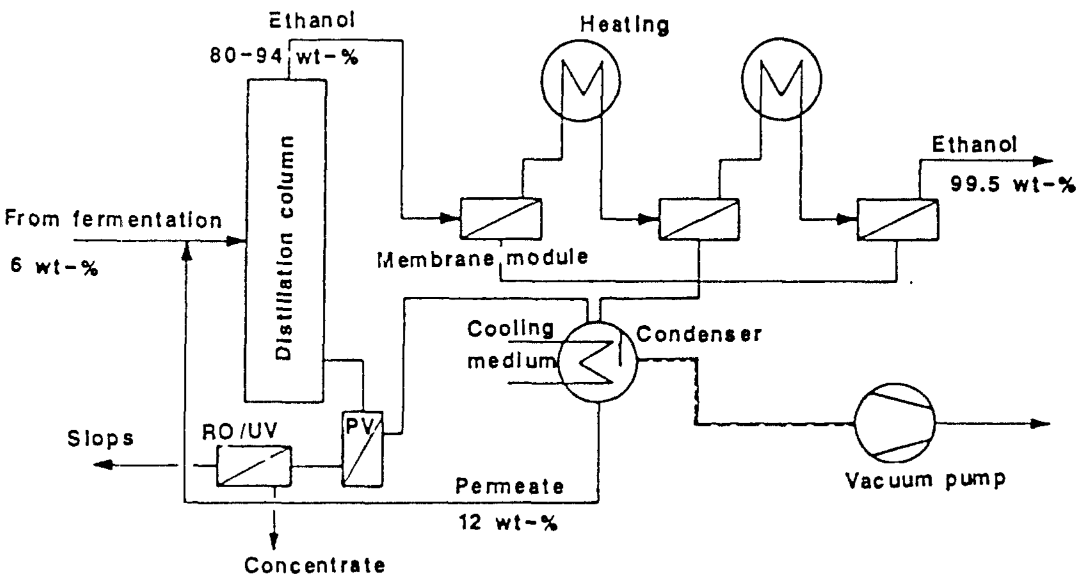
> VOC Removal from Water

> Hybrid System

Table XV Density and Osmotic Pressure Data for the System $EtOH-H_2O$ at 20°C (70)

EtOH wt.%	Density g/cm^3	Osmotic Pressure psi
0	0.9982	0
0.5	0.9973	37
1.0	0.9963	75
1.5	0.9954	111
2.0	0.9945	149
2.5	0.9936	188
3.0	0.9927	230
3.5	0.9918	272
4.0	0.9910	312
4.5	0.9902	356
5.0	0.9893	400
5.5	0.9885	440
6.0	0.9878	486
6.5	0.9870	531
7.0	0.9862	573
7.5	0.9855	621
8.0	0.9847	671
8.5	0.9840	722
9.0	0.9833	774
9.5	0.9826	829
10.0	0.9819	886
11.0	0.9805	996
12.0	0.9792	1103
13.0	0.9778	1218
14.0	0.9765	1330
15.0	0.9752	1460
16.0	0.9739	1600
17.0	0.9726	1748
18.0	0.9713	1905
19.0	0.9700	2061
20.0	0.9687	2235
22.0	0.9660	2612


optimal range for distillation
optimal range for PV
Permeate ethanol, wt-%
Feed ethanol, wt-%
10
20
30
40
50
60
70
80
90



Ethanol
80-94 wt-%
Heating
Ethanol
99.5 wt-%
From fermentation
6 wt-%
Distillation column
Membrane module
Cooling
medium
Condenser
Slops
RO/UV
PV
Permeate
12 wt-%
Vacuum pump
Concentrate

Table 42. GC-MS Analytical Results[342]

		Feed^a		Permeate^a	Boiling point, °C
		Sample 1	Sample 2		
1	Acetic acid, Ethyl Ester	0.2		4.5	77.1
2	1-Propanol, 2-Methyl-			6.8	108.0
3	1-Butanol	14.6	15.0	228.5	117.2
4	Propionic acid, Ethyl Ester	0.25	0.25	11.0	99.1
5	Ethane, 1.1-Diethoxy-			53.3	
6	1-Hexene, 4-Methyl-	1.4	0.7	34.0	87.5
7	Propionic acid	2.3	5.1	2.1	141
8	Propionic acid, 2-Methyl, Ethyl Ester	0.2		15.3	109-111
9	Hexanal	2.3	1.5	33.1	128
10	2-Furfural	2.5	1.4	0.1	161.7
11	Propanoic acid, 2-Methyl-	5.0	7.2	11.2	153.2
12	2-Hexanal	9.8	9.2	224.7	146-147
13	Butanoic acid, 3-Methyl-, Ethyl Ester	0.5	0.5	4.0	
14	1-Hexanol	7.4	6.3	91.2	158
15	1,3-Dioxolane, 2-Ethyl-			5.9	
16	1.3-Dioxolane. 2-Propyl-			0.6	
17	3-Heptanol, 3-Methyl-	0.6	0.5	5.3	163
18	Ethanone. 1-Phenyl-	100.0	100.0	100.0	
19	Hexane. 1.1-Diethoxy-			4.7	
20	Hexane, 1-(1-Ethoxyethoxy)-			1.2	
21	2-Furfural. 5-(Hydroxymethyl)-	28.4	33.2		114-116

^{a} peak ratio (%) of flavor component
to the internal standard (Ethanone, 1-Phenyl-)

Table 40. Permeate Composition and Permeate Flux Data of Pervaporation for Benzene Separation[341]

Operating conditions: temperature, 40°C; downstream pressure, 2000 Pa; feed flow, 6 L/mim; feed volume, 22.7 L; total benzene content in feed, 30–32 mL

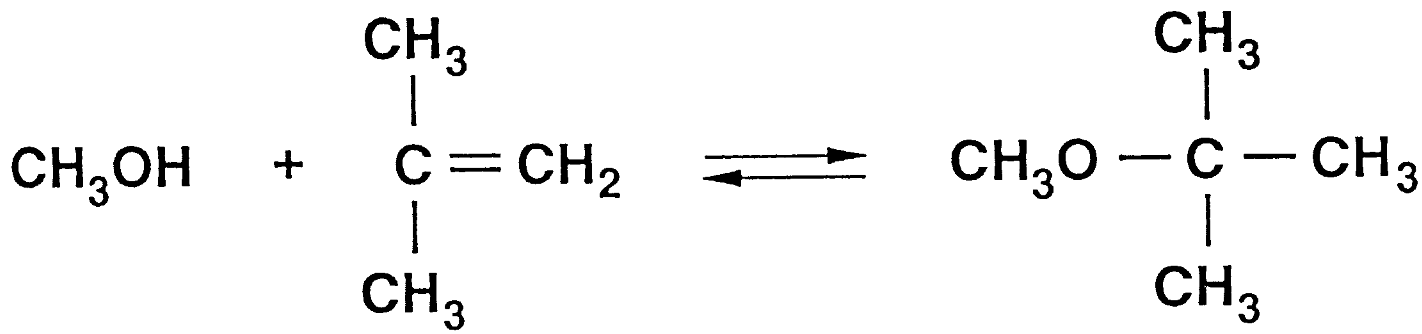
Time, h	Total permeate benzene conc., %	Permeate benzene phase, mL	Permeate aqueous phase, mL	Total weight of permeate sample, g	Permeate flux, kg/m² h
MTR-100					
1	17.2	26	11135	0.75	
2	4.3	5	102	104	0.58
3	1.0	2	101	102	0.57
4	0.2	-*	102	101	0.56
MTR-200					
2	45.4	27	29	53	0.15
4	6.7	1.8	23	24	0.068
6	2.7	0.5	23	23	0.063

*This sample contained only one phase.

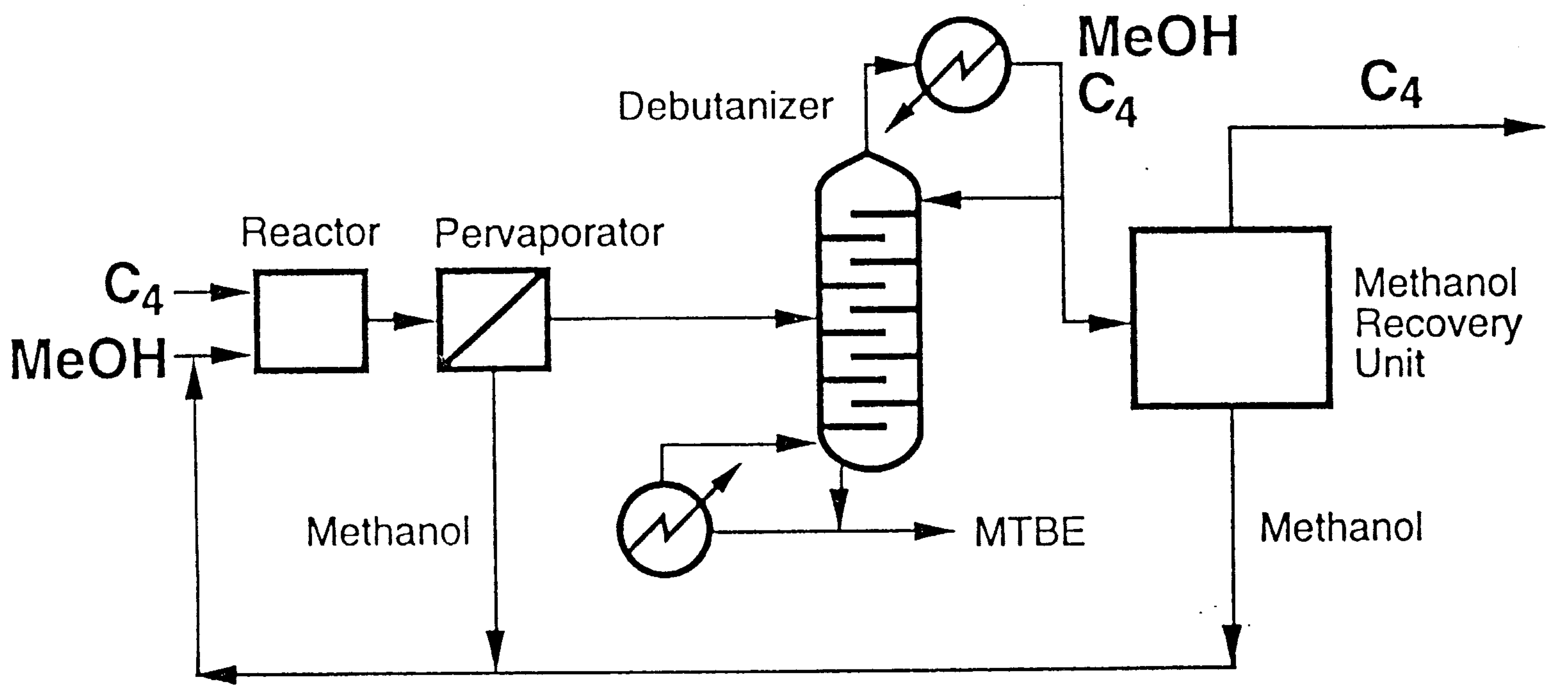
Table IX Future Potial in Pervaporation Processes (17)

Applications which are currently possible.
Dehydration of Binary Mixtures Azeotropic mixtures (isopropyl alcohol/H_2O, butyl alcohol/H_2O, tetrahydrofuran/H_2O, ethyl alcohol/H_2O) Nonazeotropic mixtures (methyl alcohol/H_2O, acetone/H_2O) Dehydration of small quantity of water (methylene chloride/H_2O, chloroform/H_2O) Dehydration of Mulicomponent Mixtures such as (ethyl alcohol/toluene/isopropyl alcohol/H_2O, ethyl esters/methyl esters, H_2O) Dehydration of Other Solutions such as (fruit juices, kerosene) Removal of Organic Solutes from Aqueous Solutions such as (phenol/H_2O, chlorinated hydrocarbons/H_2O) Removal of Organic Solvents from (waste water, fermentation broth) Dealcoholization of beer and wine

Commercial Applications Possible Within 5 years
Dehydration of Acids and Amines for example (acetic acid, hydrazine) Cleaning of Organic Solvents for example (removal of isopropyl alcohol from heptane/hexane mixture) Separation of Paraffins and Aromatic Hydrocarbons such as (benzene/hexane) Separation of Chlorinated Hydrocarbons and Hydrocarbons Separation of Normal and Branched Hydrocarbons such as (iso-octane/hexane)
Commercial Applications Are Possible Within 10 Years
Separation of Paraffins and Olefines such as (butane/butenes) Separation of Isomeric Mixtures such as (xylene mixtures) Removal of Toxic Substances From Blood Stream



METHANOL ISOBUTENE METHYL TERT-BUTYL ETHER


C4
MeOH
Reactor
Pervaporator
Methanol
Debutanizer
MeOH
C4
C4
MTBE
Methanol
Recovery
Unit
Methanol