ELSEVIER

Journal of Membrane Science 120 (1996) 149–159

journal of
MEMBRANE
SCIENCE

INTERNATIONAL UNION OF PURE
AND APPLIED CHEMISTRY

MACROMOLECULAR DIVISION
COMMISSION ON FUNCTIONAL POLYMERS*
Working Party on Membrane Nomenclature†

# TERMINOLOGY FOR MEMBRANES AND MEMBRANE PROCESSES

(IUPAC Recommendations 1996)

*Prepared for publication by*

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Reprinted from Pure & Appl. Chem., 68 (7) (1996) 1479–1489.

# Terminology for membranes and membrane processes (IUPAC Recommendations 1996)

SYNOPSIS

This project has involved assembling a basic set of terms applicable to non-living membranes and membrane processes. The terms include the key vocabulary used in the literature concerned with scientific, technical and commercial aspects of the membrane field. Processes and membranes based on synthetic or modified natural polymers as well as ceramic and metallic membranes are covered. The resultant terms and their definitions represent a core set that will allow uniform understanding and eliminate most ambiguity or confusion caused by conflicting terminology now in use. The terms and definitions selected for inclusion reflect the majority preference of the membrane community. To avoid irreconcilable differences, definitions and descriptions involving interpretations of phenomena were minimized. Some terms were deleted in cases where majority preferences were not apparent. This strategy was adopted with the understanding that the current core group of terms, which enjoy majority support, can be augmented as evolution of the field occurs.

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## CONTENTS

## *General Terms*

1. **asymmetric membrane:** membrane constituted of two or more structural planes of non-identical morphologies (§18)

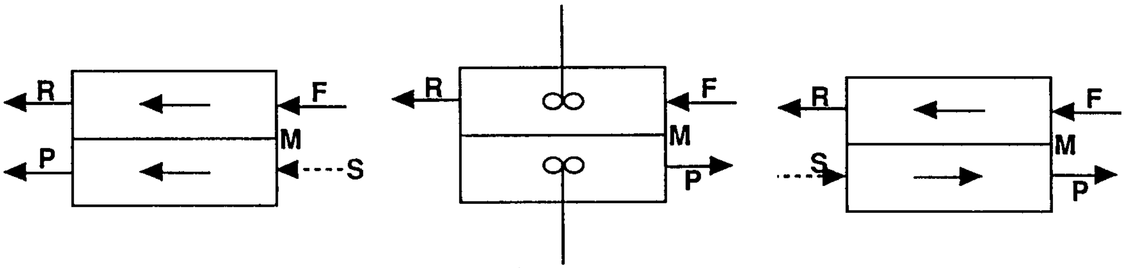
2. **co-current flow**: flow pattern through a membrane module in which the fluids on the upstream and the downstream sides of the membrane move parallel to the membrane surface and in the *same* directions (*Note*: see Fig. 1a)

3. **completely-mixed (perfectly-mixed) flow**: flow through a membrane module in which fluids on both the upstream and downstream sides of the membrane are individually well-mixed (*Note*: see Fig. 1b)

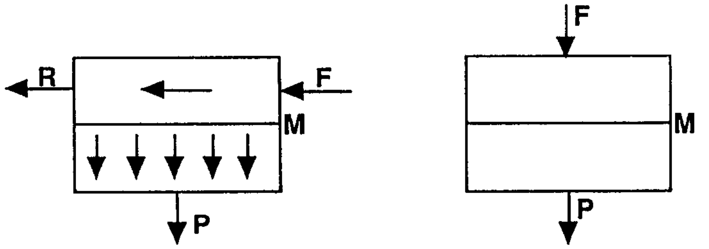
4. **composite membrane:** membrane having chemically or structurally distinct layers

5. **continuous membrane column:** membrane module(s) arranged in a manner to allow operation analogous to that of a distillation column, with each module acting as a stage

6. **counter-current flow**: flow through a membrane module in which the fluids on the upstream and downstream sides of the membrane move parallel to the membrane surface but in *opposite* directions (*Note*: see Fig. 1c)



(a) co-current flow (b) completely-mixed flow (c) counter-current flow



M = Membrane
F = Feed
P = Permeate
R = Retentate
S = Sweep stream (optional, not always present)

(d) cross flow (e) dead-end flow

Figure 1: Types of ideal continuous flows used in membrane-based separations

7. **cross flow:** flow through a membrane module in which the fluid on the ypstream side of the membrane moves parallel to the membrane surface and the fluid on the downstream side of the membrane moves away from the membrane in the direction normal to the membrane surface (*Note*: see Fig. 1d)

8. **dead-end flow:** flow through a membrane module in which the only outlet for upstream fluid is through the membrane (*Note*: see Fig. 1e)

9. **dense (non-porous) membrane:** membrane with no detectable pores

10. **downstream:** side of a membrane from which permeate emerges

11. **dry-phase separation membrane formation:** process in which a dissolved polymer is precipitated by evaporation of a sufficient amount of solvent to form a membrane structure (*Note*: Appropriate mixtures of additives are present in solution with the polymer to alter its precipitation tendency during solvent evaporation)

12. **dry-wet phase separation membrane formation:** combination of the dry- (§11) and the wet-phase formation processes (§45)

13. **dynamic membrane formation:** process in which an active layer is formed on the membrane surface by the deposition of substances contained in the fluid being treated

14. **flux, $J_i$, [kmol m$^{-2}$ s$^{-1}$]:** number of moles, volume, or mass of a specified component i passing per unit time through a unit of membrane surface area normal to the thickness direction. {*Note*: other commonly used units for $J_i$ include [m$^3$ / m$^{-2}$ s$^{-1}$], or [kg/m$^{-2}$ s$^{-1}$] or [m$^3$ (measured at standard temperature and pressure) m$^{-2}$ s$^{-1}$]}

15. **fouling:** process resulting in loss of performance of a membrane due to the deposition of suspended or dissolved substances on its external surfaces, at its pore openings, or within its pores

16. **homogeneous membrane:** membrane with essentially the same structural and transport properties throughout its thickness

17. **Langmuir-Blodgett (LB) membrane:** synthetic composite membrane formed by sequential depositing of one or more monolayers of surface-active component onto a porous or nonporous support

18. **membrane:** structure, having lateral dimensions much greater than its thickness, through which mass transfer may occur under a variety of driving forces

19. **membrane compaction:** compression of membrane structure due to a pressure difference across its thickness

20. **membrane conditioning (pretreatment):** process carried out on a membrane after the completion of its preparation and prior to its use in a separation application (*Note 1*: thermal annealing to relieve stresses or pre-equilibration in a solution similar to the feed stream it will contact are examples of conditioning treatments) [*Note 2*: conditioning treatments differ from post-treatments (§25), since the latter occur before exposure to feed type solutions, while conditioning may occur using actual feed solutions]

**21. membrane distillation:** distillation process in which the liquid and gas phases are separated by a porous membrane, the pores of which are not wetted by the liquid phase

**22. membrane module (cell):** manifold assembly containing a membrane or membranes to separate the streams of feed, permeate, and retentate (*Note*: see Fig. 2a-c)

**23. membrane partition (distribution) coefficient:** parameter equal to the equilibrium concentration of a component $\left(c_i^{(m)}\right)$ in a membrane divided by the corresponding equilibrium concentration of the component in the external phase in contact with the membrane surface, $c_i^{(e)}$. $\left(\text{viz., } K = c_i^{(m)} / c_i^{(e)}\right)$

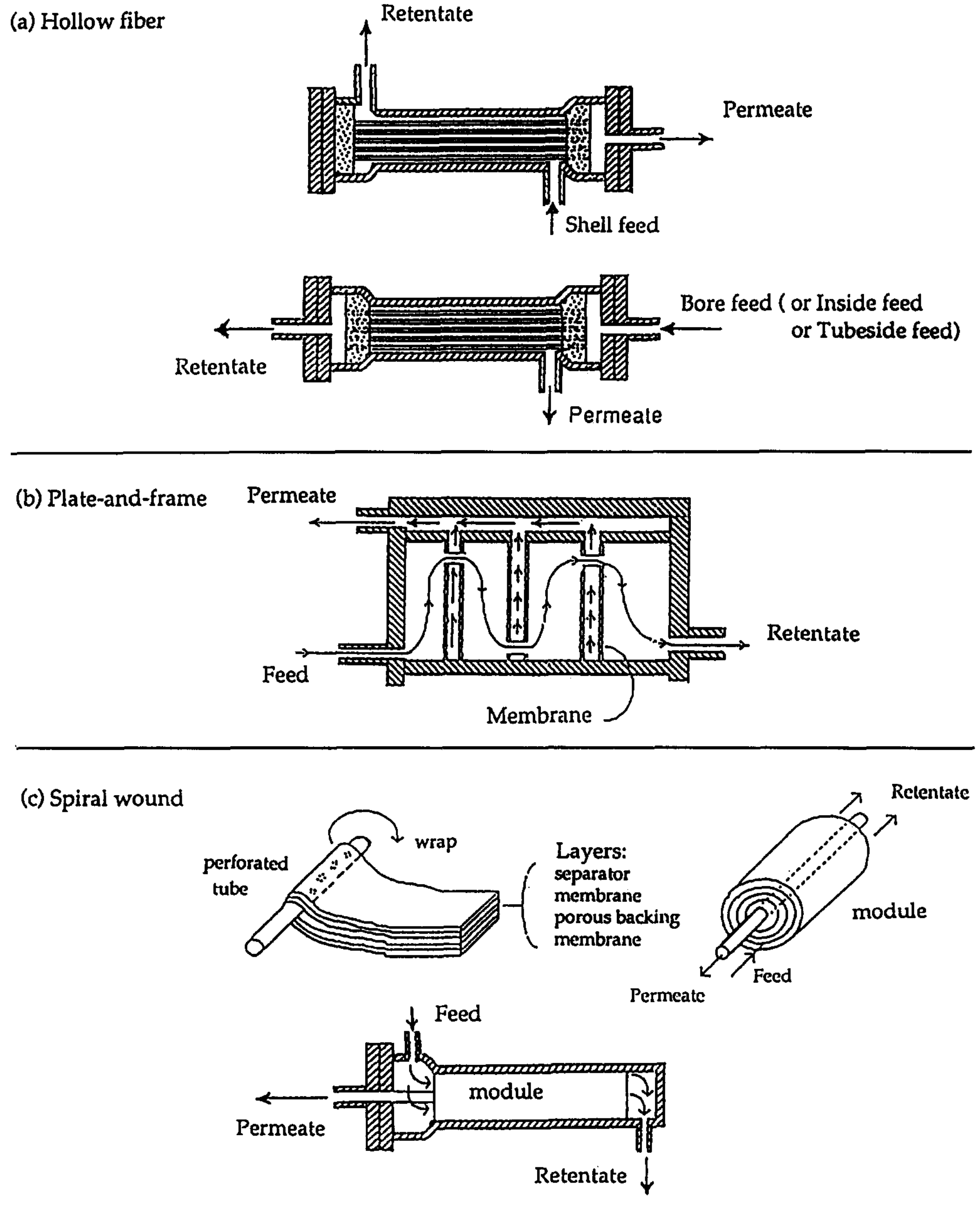


Figure 2: Types of modules used in membrane-based separation.

24. **membrane physical aging:** change in the transport properties of a membrane over a period of time due to physical chemical structural alterations

25. **membrane post-treatment**: process carried out on a membrane after its essential structure has been formed but *prior* to its exposure to an actual feed stream (§20.)

26. **membrane reactor**: device for simultaneously carrying out a reaction and membrane-based separation in the same physical enclosure

27. **penetrant (permeant)**: entity from a phase in contact with one of the membrane surfaces that passes through the membrane

28. **permeability coefficient, $P_i$, [kmol m $m^{-2}$ $s^{-1}$ $kPa^{-1}$]:** parameter defined as a transport flux, $J_i$, per unit transmembrane driving force per unit membrane thickness, viz., $P_i = J_i$ / [(transmembrane driving force of component $i/\ell$] {*Note*: other commonly used units for $P_i$ include [$m^3$ m $m^{-2}$ $s^{-1}$ $kPa^{-1}$ ], [$m^3$ (measured at standard temperature and pressure m $m^{-2}$ $s^{-1}$ $kPa^{-1}$ ] or [kg m $m^{-2}$ $s^{-1}$ kPa ]}

29. **permeance (pressure normalized flux), [kmol $m^{-2}$ $s^{-1}$ $kPa^{-1}$]:** transport flux per unit transmembrane driving force, viz., $P_i/\ell$ (§28) {*Note*: other commonly used units include [$m^3$ $m^{-2}$ $s^{-1}$ kPa ], [kg $m^{-2}$ $s^{-1}$ $kPa^{-1}$ ], or [$m^3$ (measured at standard temperature and pressure) $m^{-2}$ $s^{-1}$ $kPa^{-1}$]}

30. **permeate:** stream containing penetrants that leaves a membrane module (*Note*: see Figs. 1 and 2)

31. **perstraction**: separation process in which membrane permeation and extraction phenomena occur by contacting the downstream with an extracting solvent

32. **relative recovery, $\eta_{n,\mathrm{B}}$ (substance efficiency):** amount-of-substance of a component B collected in a useful product, $\eta_{\mathrm{B,out}}$, divided by the amount-of-substance of that component entering the process, $\eta_{\mathrm{B,in}}$: $\eta_{\eta,\mathrm{B}} = \eta_{\mathrm{B,out}} / \eta_{\mathrm{B,in}}$ [*Note*: in membrane separations, the useful product may be either the retained material (or retentate) or the permeated material (or permeate)]

33. **rejection factor, R:** parameter equal to one minus the ratio the concentrations of a component (i) on the downstream and upstream sides of a membrane {*Note 1*: $R = 1 - [(c_i)\mathrm{downstream} / (c_i)\mathrm{upstream}]$} [*Note 2*: concentrations may be either in the bulk ("Apparent Rejection Factor") or at the membrane surface ("Intrinsic Rejection Factor")] [*Note 3*: rejection factor refers to a local relationship between upstream and downstream concentrations while retention factor (§35) and relative recovery (§32) refers to feed and retentate or permeate leaving the module]

34. **retentate (raffinate):** stream that has been depleted of penetrants that leaves the membrane modules without passing through the membrane to the downstream

35. **retention factor, $r_F$:** parameter defined as one minus the ratio of permeate concentration to the retentate (§34) concentration of a component (*i*) {*Note 1:* $r_F = 1 - \left[(c_i)_p / (c_i)_r\right]$} [*Note* 2. "p" and "r" refer to permeate (§30) and retentate (§34). See Fig. 1] [*Note 3*: Compare rejection factor. (§33)]

36. **selective membrane skin:** region, often located at the upstream face of an asymmetric membrane, that forms a thin, distinguishable layer primarily responsible for determining the permeability of the asymmetric membrane

37. **separation coefficient, $S_C(AB)$:** ratio of the compositions of component A and B in the downstream relative to the ratio of compositions of these components in the upstream {*Note 1*: For example, if compositions are expressed in mole fractions ($X_A$ and $X_B$), $S_C(AB) = [X_A/X_B]_{downstream} / [X_A/X_B]_{upstream}$} (*Note 2:* The separation coefficient can also be defined equivalently in terms of concentrations in the downstream and upstream, since only ratios are involved) [*Note 3:* The separation coefficient refers to a local relationship between concentrations on the upstream (§44) and downstream (§10) concentrations while the separation factor (§38) refers to retentate (§34) and permeate (§30) leaving the module]

38. **separation factor, $S_F(AB)$:** ratio of the compositions of components A and B in the permeate relative to the composition ratio of these components in the retentate {*Note 1:* For example, $S_F(AB) = [X_A/X_B]_{Permeate} / [X_A/X_B]_{Retentate}$} (*Note 2:* The separation factor can also be defined in terms of concentrations in the permeate and retentate since only ratios are involved. *Note*: see Fig. 1) [*Note* 3. Compare separation coefficient. (§37)]

39. **sol-gel membrane formation:** multistep process for making membranes by a reaction between two chemically multifunctional materials, dissolved in a solvent, that results in a network structure with solvent retained in the network followed by heat treatment to achieve a desired pore structure

40. **stage cut:** parameter defined as the fractional amount of the total feed entering a membrane module that passes through the membrane as permeate (*Note*: see Fig. 1)

41. **synthetic (artificial) membrane:** membrane formed by a process not occurring in nature

42. **thermally-induced phase-separation membrane formation:** process in which a dissolved polymer is precipitated or coagulated by controlled cooling to form a membrane structure

43. **track-etch membrane formation:** process for forming porous membranes with well-defined pores by exposing a dense film to ion bombardment followed by etching of the damaged region (*Note*: Usually produces pores with a narrow size distribution)

44. **upstream:** side of a membrane into which penetrants enter from the feed stream

45. **wet-phase separation membrane formation:** process in which a dissolved polymer is precipitated by immersion in a non-solvent bath to form a membrane structure

## *Carrier-Mediated (Facilitated) Separations*

46. **anchored (bound) carrier:** distinct species bonded chemically to fixed sites within a membrane for the purpose of increasing the selective sorption and flux of a specific component in a feed stream relative to all other components

47. **carrier complexation coefficient, $K_c$, [kmol m$^{-3}$]:** parameter defined as the ratio of the rate constants for the second order complexation and first order decomplexation reaction between a carrier and a penetrant: viz., A + M = AM [*Note 1:* $K_c = k_c/k_d$, where A & M, resp., are a penetrant and a carrier site within a membrane (see note 2)] [*Note 2:* both anchored carrier sites (§46) and mobile carrier sites (§59) are possible]

48. **carrier complexation:** phenomenon in which carrier molecules form a coordinated structure with penetrant molecules

49. **carrier deactivation:** chemical transformations involving a carrier entity which render it less capable of undergoing the desired interaction with a penetrant

50. **carrier leaching:** loss of carrier due to its partitioning by mass transport into one or both external phases

51. **carrier-mediated (facilitated) transport:** process in which chemically distinct carrier species (§46, §59) form complexes with a specific component in the feedstream, thereby increasing the flux (§14) of this component relative to other components

52. **complexation rate constant, $k_c$, [kmol$^{-1}$ m$^3$ s$^{-1}$]:** carrier complexation rate divided by the product of the local concentrations of the carrier and the complexable component, viz., $k_c$ = (complexation rate)/[$(c)_{\text{carrier}}(c)_{\text{complexable component}}$] where concentrations are given in [kmol m$^{-3}$] and complexation rate is given in [kmol m$^{-3}$ s$^{-1}$]

53. **coupled transport:** process in which the flux of one component between the upstream and downstream is linked to the flux of a second component

54. **Damkohler number:** dimensionless number equal to the characteristic time ($\ell^2/D_{AM}$) for diffusion of complexed component across a membrane of thickness, $\ell$, divided by the characteristic time ($k_d^{-1}$) for the decomplexation reaction between a carrier (M) and a complexed penetrant, A, viz., $\ell^2/(D_{AM}k_d)$ when $D_{AM}$ is the effective diffusion coefficient of the complexed carrier entity in the membrane

55. **decomplexation rate constant, $k_d$, [s$^{-1}$]:** ratio of the decomplexation rate to the product of the local concentration of the complexed carrier, viz., $k_d$ = (decomplexation rate) / $(c)_{\text{complexed carrier}}$ {*Note*: typical units for decomplexation rate are [kmol m$^{-3}$ s$^{-1}$], and for complexed carrier are [kmol m$^{-3}$]]

56. **enhancement factor, $\varepsilon$:** ratio of the flux of a component, *i* (§14) across a carrier-containing membrane divided by the transmembrane flux of the same component across an otherwise identical membrane without carrier
{*Note*: $\mathcal{E}=\left[(J_i)_{\text{with carrier}}/(J_i)_{\text{without carrier}}\right]$}

57. **facilitation factor:** parameter equal to the enhancement factor (§56) minus one (*Note*: $\mathcal{F}=\mathcal{E}-1$)

58. **liquid membrane:** liquid phase existing either in supported or unsupported form that serves as a membrane barrier between two phases

59. **mobile carrier:** distinct species moving freely within a membrane for the purpose of increasing the selective sorption and flux of a specific component in a feed stream relative to all other components

60. **uphill transport:** process in which diffusion of a component occurs from a less concentrated feed stream to a more concentrated permeate stream

## *Dialysis, Nanofiltration, Ultrafiltration, and Microfiltration Separations*

61. **backflush:** temporary reversal of the direction of the permeate flow

62. **bubble point:** pressure at which bubbles first appear on one surface of an immersed porous membrane as gas pressure is applied to the other surface

63. **cake layer:** layer comprised of rejected particulate materials residing on the upstream face of a membrane

64. **concentration polarization:** concentration profile that has a higher level of solute nearest to the upstream membrane surface compared with the more-or-less well-mixed bulk fluid far from the membrane surface

65. **concentration factor:** ratio of the concentration of a component i in the retentate to the concentration of the same component in the feed {*Note 1:* $c_F = \left[(c_i)_{\text{retentate}}/(c_i)_{\text{feed}}\right]$ (*Note*: see Fig. 1)} [*Note 2:* Compare retention factor (§35)]

66. **dialysis:** membrane process in which transport is driven primarily by concentration differences, rather than by pressure or electrical-potential differences, across the thickness of a membrane

67. **dialysis permeability coefficient:** permeability coefficient (§28) based on a transmembrane driving force expressed in terms of the concentration difference of a given component

68. **gel fouling layer:** highly swollen fouling layer comprising a three-dimensional, possibly network, structure residing at the surface of a membrane

69. **hemodialysis:** dialysis process (§66) in which undesired metabolites and toxic by-products, such as urea and creatine, are removed from blood

70. **hemofiltration:** ultrafiltration process (§76) in which undesired metabolites and toxic by-products, such as urea and creatine, are removed from blood

71. **hindered transport:** combined partition, diffusion and convection process in which the effective partition, diffusion and viscous drag coefficients in a restricted environment depend upon the ratio of the effective radius of the penetrant molecule to that of the pore

72. **microfiltration:** pressure-driven membrane-based separation process in which particles and dissolved macromolecules larger than 0.1 μm are rejected

73. **molecular-weight cutoff:** molecular weight of a solute corresponding to a 90% rejection coefficient (§33) for a given membrane

74. **nanofiltration:** pressure-driven membrane-based separation process in which particles and dissolved molecules smaller than about 2 nm are rejected

75. **ultrafiltration:** pressure-driven membrane-based separation process in which particles and dissolved macromolecules smaller than 0.1 μm and larger than about 2 nm are rejected

## *Electrically Mediated Separations*

76. **anion-exchange membrane:** membrane containing fixed cationic charges and mobile anions that can be exchanged with other anions present in an external fluid in contact with the membrane

77. **bipolar membrane:** synthetic membrane containing two oppositely charged ion-exchanging layers in contact with each other

78. **cation-exchange membrane:** membrane containing fixed anionic charges and mobile cations which can be exchanged with other cations present in an external fluid in contact with the membrane

79. **charge-mosaic membranes:** synthetic membrane composed of two-dimensional or three-dimensional alternating cation- and anion-exchange channels throughout the membrane

80. **Donnan exclusion:** reduction in concentration of *mobile* ions within an ion exchange membrane due to the presence of *fixed* ions of the same sign as the mobile ions

81. **electro-dialysis:** membrane-based separation process in which ions are driven through an ion-selective membrane under the influence of an electric field

82. **electro-osmosis:** process by which water is transported across the thickness of an anion-exchange (§76) or cation-exchange membrane (§78) under an applied electric field

83. **limiting current density:** current density at which dramatic increases in resistance are observed in an ion exchange membrane system under the influence of an applied electric field between the upstream and downstream

## *Gas, Vapor and Pervaporation Separations*

84. **ideal separation factor:** parameter defined as the ratio of the permeability coefficient of component A to that of component B and equal to the "separation factor" (§37) where a perfect vacuum exists at the downstream membrane face for gas and vapor permeation systems

85. **pervaporation:** membrane-based process in which the feed and retentate streams are both liquid phases while permeant emerges at the downstream face of the membrane as a vapor

86. **solution-diffusion (sorption-diffusion):** molecular-scale process in which penetrant is sorbed into the upstream membrane face from the external phase, moves by molecular diffusion in the membrane to the downstream face and leaves into the external gas, vapor or liquid phase in contact with the membrane

87. **sweep:** nonpermeating stream directed past the downstream membrane face to reduce downstream permeant concentration

## *Reverse Osmosis Separations*

88. **brackish water:** term used to indicate water having a total dissolved-solids content that is less than that of sea water but above that of potable water

89. **feed pretreatment**: process carried out on a crude feed stream, prior to feeding to a membrane separation system, to eliminate objectionable components such as biological agents and colloids that might impede the stable operation of the membrane

90. **permeate post-treatment:** one or more final conditioning steps to improve permeate quality, e.g., contacting with anion exchange resins to remove trace ions in the permeate of a reverse osmosis product stream

91. **potable water:** term used to indicate water having a total dissolved solids content of less than 500 ppm with a sufficiently low level of biological agents, suspended solids, organic odour- and colour-generating components to be safe and palatable for drinking

92. **reverse osmosis:** liquid-phase pressure-driven separation process in which applied transmembrane pressure causes selective movement of solvent against its osmotic pressure difference

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