

## Index

### a

absorption, 2, 59, 70, 183, 186, 188, 219, 303, 374, 376  
 activation energy, 61, 102, 103, 107, 133, 242  
 adsorption, 2, 31, 72, 73, 122, 128, 129, 131, 135, 160, 170, 201, 221, 232, 234, 250, 261, 281, 319, 324, 330  
 advanced oxidation process (AOP), 275  
 air gap membrane distillation (AGMD), 276, 277, 279  
 alumina, (Al<sub>2</sub>O<sub>3</sub>), 16, 26, 27, 34, 51, 53, 57, 66, 155, 204, 218, 236  
 aluminium, 26, 27  
 aluminophosphates (AlPO), 70  
 anaerobic MBRs (anMBRs), 287  
 atmospheric pressure chemical vapour deposition (APCVD), 58, 62, 64  
 atomic force microscopy (AFM), 150, 178–181  
 attenuated total reflection Fourier transform infrared spectroscopy (ATR-FTIR), 187

### b

*Bacillus cereus*, 268  
 backscattered radiation, 182–185  
 barium cerate (BaCeO<sub>3</sub>), 237  
 barium perovskite oxides, 243  
 barium zirconate, 243  
 bending test, 192, 195  
 bend stress, 195  
 best management practices (BMPs), 267  
 bilge water, 296  
 biological oxygen demand (BOD), 286, 290, 291  
 bovine serum albumin (BSA), 304  
 brackish water, 267, 278, 279  
 Brownian motion, 103  
 Brunauer–Emmett–Teller (BET) method, 160  
 bubble point test, 156, 157

### c

calcination, 189, 257, 363  
 calcium oxide, 2  
*Campylobacter jejuni*, 268, 304  
 capillary condensation, 91, 125, 131–133, 138  
 capital expenses (CapEx), 217, 367, 372  
 Carman–Kozeny equation, 116, 154  
 Carnot cycle, 239  
 caseins, 301, 302  
 catalytic membrane reactor (CMR), 250, 254–259  
 catalytic membranes, 256, 258  
 cathode reactions, in acidic environment, 239  
 CaTiO<sub>3</sub> crystal structure, 237  
 caustic agents, 21  
 cellulose acetate (CA), 10  
 centreless grinding, 54  
 CeramiCell<sup>®</sup>, 237  
 ceramic filters, 2, 3, 266, 271–274, 319  
 ceramic fuel cells, 246  
 ceramic MBRs. *see* ceramic membranes reactors  
 ceramic membranes  
 – advantages, 22, 23, 25  
 – intermediate/top layers, 54–58  
 – limitations, 25  
 – reactors 250  
 – Robeson diagram, 24  
 – tailor-made, 23  
 – technical specifications of, 371  
 – vs. polymer membranes, 22–25  
 ceramics  
 – layman's definition, 2  
 – slurry content, 39  
 Chapman–Enskog theory, 100  
 chemical contaminants, 275  
 chemical oxygen demand (COD), 286, 290, 291  
 chemical vapour deposition (CVD), 1, 28, 55–66, 70, 236, 261

- chemical vapour infiltration (CVI), 261  
 chemisorption, 65, 111, 279  
 citric acid, 21  
 cleaning, 20–22  
 cleaning-in-place (CIP), 22, 23, 313  
 cleaning-out-of-place (COP), 22  
 coarsening, 48  
 colloids, 66  
 compact tension method, 195  
 composite membranes, 260  
 compressive strain, 192  
 concentration polarization model, 118–120  
 confocal microscopy, 173  
 confocal Raman spectroscopy, 189  
 confocal scanning laser microscopy (CSLM), 150, 173  
 contact angles, 150, 157, 158, 160, 162, 196, 197  
 continuous stirred-tank reactors (CSTRs), 250, 251  
 convection, 95  
 convective mass transfer, 91, 111–113  
 conventional activated sludge (CAS), 290  
 counter-diffusion, geometry, 65  
 $\text{Cr}_2\text{O}_3/\text{Al}_2\text{O}_3$  catalyst, 253  
 cross-flow microfiltration (CFMF) technology, 322  
 cryogenic distillation, 221  
*Cryptosporidium parvum*, 168, 266  
 crystallization, 2, 31, 70, 71, 73  
 CsNaX zeolite catalyst, 263  
 CSR Qingdao Sifang Company (CSR Sifang), 244  
 cubic boron nitride (CBN), 54
- d**
- Dalton's law, 93  
 Darcy equation, 116, 191  
 DD3R zeolite membrane, 253  
 Debye length, 201  
 deflocculants, 36  
 deformations, 193, 194  
 dehydration, 34, 252, 253, 280–282, 284–286, 298  
 Della Toffola membranes, for wine clarification, 325  
 dense electrolyte membranes, 246  
 dense membranes, 11, 193  
 deprotonation, 199  
 dextrans, 171  
 diatomic earth (DE), 314  
 dibutyl-*o*-phthalates, 38  
 dielectric permittivity, 198  
 differential scanning calorimeter (DSC), 163  
 diffusion, 8, 46, 48, 61, 65, 95, 98, 101, 103, 115, 124, 221, 261  
 – Ashby, 47  
 – coefficients, 99, 102  
 – in gases, 91, 99–103  
 – lattice, 47  
 – in liquids, 103–105  
 – mass fluxes, 95, 96  
 – rate, 44  
 – in solids, 105–107  
 – solution-diffusion theory, 234  
 – turbulent, 95  
 – velocity, 95  
 dilution steam water (DSW), 373  
 dip coating, 56  
 dipole–electric dipole, 189  
 direct contact membrane distillation (DCMD), 276  
 dispersed oil, 293  
 dissolved oxygen (DO), 316  
 distillation, 2, 23, 221, 250, 275, 276. *see also* membrane distillation (MD)  
 Donnan potential, 200  
 drilling, 292  
 drinking water treatment plants (DWTPs), 368, 369  
 dry gel conversion method, 72  
 dry membrane, 157, 161, 178  
 dynamic viscosity, 103, 114, 116, 117, 154, 198
- e**
- economic considerations, in manufacturing/ applications, 355  
 – Atech Innovations GmbH (Germany), 362–365  
 – LiqTech A/S (Denmark), 365–368  
 – Metawater Co. (Japan), 368–370  
 – petrochemical wastewater, pretreatment of, 370–373  
 – Techno-Economic Analysis of CO<sub>2</sub> capture from flue gases (France), 373–376  
 elastic deformation, 194  
 electrical double layer (EDL), 198  
 electrochemical impedance spectroscopy (EIS), 199  
 electron energy loss spectroscopy (EELS), 182  
 electronic conductivity, 139, 140, 237, 249  
 electroosmotic flow, 198  
 electrostatic repulsion, 67, 201  
 elongation tests, 194  
 endocrine disruptive compounds (EDCs), 274  
 energy demand, 2

- energy-dispersive X-ray spectroscopy (EDS/EDX), 150  
 see activation energy, 102  
*Enterococcus faecalis*, 268  
 EPA regulations, 294  
*Escherichia coli*, 268  
 ethanol, 281, 282  
 ethylbenzene, 281  
 ethyl-2-cyano-3-phenylacrylate, 263  
 ethylenediamine, 72  
 ethylenediamine tetra acetic acid (EDTA), 22  
 ethylene glycol, 72  
 4-ethylguaiaicol, 326  
 4-ethylphenol, 326
- f**
- fast Fourier Transform (FFT), 181  
 feasibility, 152, 371, 373, 384  
 feed spacer, 16  
 fermentation, 282, 284, 300, 315–318, 321–324  
 Fickian diffusion, 128  
 Fick's law, 96–99, 110  
 filtration, 71, 91, 168, 198  
 Fischer–Tropsch process, 256, 264  
 flat-sheet technology, 289  
 flue gases, 227, 357, 373  
 fluoroalkylsilanes, 279  
 fluorodecyltriethoxysilane, 279  
 fluxes, 115, 117, 118, 124–125  
 – through non-porous membranes, 138–142  
 fossil fuels, 3  
 fouling, 18–20, 21, 123, 181, 187  
 Fourier transform infrared spectroscopy (FTIR), 150, 187  
 Fourier transform Raman spectroscopy (FT-Raman), 188, 189  
 free energy, 156  
 friction coefficient, 103  
 fuel cells, 3, 55, 239–245
- g**
- gas adsorption–desorption, 150, 160, 161  
 gas–liquid permporometry, 150, 161, 162  
 gas permeability, 136  
 – test, 154, 155  
 gas separation, 3, 10, 14, 221–232  
 gel formation, 19  
 German company Fraunhofer IKTS, 282  
 Gibbs–Thomson equation, 163  
 grain size, 51  
 green body, 34, 36  
 green cast, 36  
 grinding, 53, 54
- Grotthuss mechanism, 242  
 groundwater resources, 292
- h**
- Hagen–Poiseuille equation, 116, 154  
 H<sub>2</sub>–CO<sub>2</sub> membranes, 230  
 heat transfer, 92  
 Helmholtz–Smoluchowski approximation, 198  
 Herring's scaling law, 48  
 high-pressure membranes, 150  
 high-resolution techniques, 174  
 hold-up volume, 17  
 homogenization, 298  
 honeycomb configuration, 17  
 hopping model, 130  
 hybrid membranes, 68  
 hydraulic residence time, 170  
 hydrodynamic hindrance, 104  
 hydrodynamic model, 103, 130  
 hydrogen, 3, 155–156, 232–239  
 hydrolysis, 21, 58, 64, 67  
 hydrophilicity, 70, 150, 156, 157, 196, 197, 253  
 hydrophobicity, 20, 157, 196, 197, 279, 284  
 hydrothermal treatment, 55  
 hydroxyethyl cellulose, 45  
 hysteresis, 161
- i**
- ideal gas equation, 93  
 ideal initial slurry, 173  
 impedance spectroscopy, 198  
 inert membrane reactor (IMR), 250, 254, 261  
 infrared spectroscopy, 186  
 inherently catalytic membranes, 258  
 inside-out mode, 17  
 integrity tests, 170  
 intellectual property rights (IPR), 358  
 interfacial tension, 196  
 internal grinding, 54  
 'inverse spectroscopy' instruments, 186  
 ion-transfer mechanism, 139  
 iso-propyl propanoate, 253  
 isothermal membrane distillation, 278  
 isothermal-stage sintering, 51  
 isotropic, 12  
 – membrane, 1, 3  
 isovaleric acid, 325, 326
- j**
- jet fuel, 370  
 juice–pulp suspension, 95

**k**

Keeling curve, 225  
 Kerasep<sup>®</sup> membrane module, 17  
 Kieselguhr (DE) filtration, 314, 322, 326  
 Kirkendall effect, 107  
 Knoevenagel condensation, 263  
 Knudsen diffusion, 91, 101, 125–127, 132, 137, 154, 231, 236, 261  
 Knudsen number, 101  
 Knudsen transport mechanism, 258  
 Kozeny theory, 117  
 Kröger–Vink notation, 242

**l**

lactose, 303  
 lanthanum strontium magnesium gallate (LSGM), 246  
 lapping, 53  
 Lennard-Jones potential, 100  
 life cycle assessment (LCA), 358, 360–362  
 linearity, 152  
 liquid–liquid displacement (LLD), 150, 158  
 liquid pre-cheese concentration (LPC), 302  
 liquid separation/purification, 265–297  
 – fermented food industry, 314, 315–326  
 – in food applications, 297–308, 310, 314  
 liquid–vapour interfaces, 132  
 lithium aluminosilicates, 272  
 lithium dodecylsulfates, 171  
 log removal values (LRVs), 268

**m**

macropores, 11  
 magnesium oxide (MgO), 38  
 malt, 315, 317  
 market size, 376–383  
 mass-average velocity, 94, 95  
 mass balance equation, 107, 119  
 mass diffusivity, 99, 113  
 mass flux, 94, 95  
 mass fraction, 92, 93  
 mass transfer, 91, 92  
 Maxwell's equilibrium formulae, 100  
 mechanical strength tests, 192–195  
 MEDAL commercial polymeric membrane module, 234  
 Membralox<sup>®</sup> GP membranes, 17, 121  
 membrane–air interface, 44  
 membranes  
 – morphology of, 11–15, 49, 259  
 – reactors, 250, 251, 264, 265  
 – separation (*see* membrane separation, basics of)

– thickness (*see* thickness)  
 membrane distillation (MD), 276  
 membrane electrode assembly (MEA), 240  
 membrane separation, basics of, 4–10, 94  
 mercury intrusion porosimetry (MIP), 159  
 mercury porosimetry, 150, 159, 160  
 mesopores, 11, 137, 152, 162, 165  
 metal alkoxide, 66  
 metal-organic frameworks (MOFs), 227  
 metal oxides, 197  
 methanol/methyl t-butyl ether (MTBE), 81  
 methyl cellulose, 45  
 MEUF. *see* micellar-enhanced ultrafiltration (MEUF)  
 MF. *see* microfiltration (MF)  
 micellar-enhanced ultrafiltration (MEUF), 295  
 micelles, 22, 295, 299, 301  
 Michelson interferometer, 186  
 microcracks, 51  
 microfiltration (MF), 9, 10, 150, 305  
 micropores, 11, 28, 130, 131, 133, 152, 219, 236, 261  
 micro-Raman spectrometer, 188  
 microreactors, 263  
 microscopy methods, 150, 172  
 mixed ionic-electronic conducting membranes (MIECs), 249  
 mixed liquor suspended solids (MLSS), 290  
 mixed matrix membranes (MMMs), 73  
 molecular sieving, 67, 91, 125, 133–135  
 molten carbonate fuel cells (MCFCs), 240, 243  
 monoethanolamine (MEA), 228  
 multistage flash distillation (MSF), 277

**n**

NaA/NaY zeolites, 283–285  
 nanofiltration (NF), 1, 9  
 naphtha, 370  
 neutralizing water-soluble contaminants, 266  
 Ni-based alloys, 241  
 Ni–Gd-doped ceria (GDC), 247  
 nitridation, 64  
 nuclear magnetic resonance (NMR), 150, 164, 165  
 nuclear magnetic resonance cryoporometry (NMRC), 163  
 nuclear reaction analysis (NRA), 181  
 nucleation, 72

**o**

offshore transportation systems, 293  
 Ohm's law, 101  
 oil–water separation, 291, 294, 296

- operating expenses (OpEx), 218, 234, 286, 370
- original equipment manufacturers (OEMs), 363
- Ostwald ripening, 49
- oxidative dehydrogenation, 251
- oxygen, 249
- flux, 155
  - partial pressure, 155
  - permeation tests, 155
- o-xylene, 281
- p**
- PACE (Program for Accessible Health, Communication and Education), 274
- packing densities, 35
- palladium membranes, 235
- parallel diffusion, 101, 102
- parallel transport model, 134–137
- partial densities, 92, 95
- partial pressure, 155
- particle-induced X-ray emission (PIXE), 181
- particle–liquid separation, 9
- passive barrier, 1
- pasteurization, 298, 305, 306
- high-temperature short-time (HTST), 305
  - ultrahigh-temperature (UHT), 305
  - ultra-pasteurization (UP), 305
- payback period (PBP), 373
- PCFC membranes, 242, 243
- peel strength test, 195
- permeability, 136, 141, 153
- coefficients, 154
  - tests, 153
- pervaporation, 70, 280, 282
- pharmaceuticals and personal care products (PPCPs), 274
- phase separation/leaching method, 236
- phenyltriethoxysilane, 257
- physical parameters, membrane characterization, 150, 189, 197–201
- physical vapour deposition (PVD), 55
- physico-chemical parameters, 129
- physisorption, 160
- plasma-enhanced chemical vapour deposition (PECVD), 58
- plastic deformations, 47, 194
- plasticizers, 38
- plate-and-frame modules, 15
- plug-flow reactors (PFRs), 250, 252, 262
- Poiseuille flow, 154
- polarization model, 119
- polishing, 53
- political, economic, social and technological (PEST), 358–360
- polyacrylonitrile (PAN), 10
- polyamide (PA), 10
- poly(butyl methacrylate) (PBMA), 38
- polycrystalline diamond (PCD), 54
- polydiallyldimethylammonium (PDDA) chloride, 71
- polydimethylsiloxane (PDMS), 187, 221
- polyelectrolytes, 198
- polyethersulfone (PES), 10
- polyethylene (PE), 289
- polyethylene glycols (PEGs), 38, 171
- polymeric MF/UF membranes, 10
- polymer swelling, 188
- poly(propylene carbonate) (PPC), 38
- polypropylene (PP) hydrophobic polymers, 278
- polysulfone (PS), 10
- polytetrafluoroethylene (PTFE) hydrophobic polymers, 278
- polyvinyl acetate (PVAc), 38, 45
- polyvinyl alcohol, 45
- polyvinyl butyral (PVB), 38
- polyvinyl chloride (PVC), 356
- polyvinylidene fluoride (PVDF), 10
- hydrophobic polymers, 278
- pore blocking model, 123–125
- pore charge, 198, 200
- pore resistances, 138
- pore size, 11–14, 26, 32, 38, 52, 56, 57, 73, 101, 102, 129–135, 150–159, 171, 200, 201
- diameter, 157, 236, 255, 301
  - distribution, 11, 101, 150, 152, 153, 157, 158, 170, 174, 236
  - length, 116, 138, 154
  - shape and connectivity, 19, 149, 164, 178, 190, 191
  - tests, groups of, 152
- Potters for Peace (PFP), 272, 273
- pouring grains, 35
- powdered activated carbon (PAC) particles, 170
- power spectral density (PSD), 181
- pre-combustion technology, 229
- pressure swing adsorption (PSA), 221
- pristine membrane, 152
- project appraisal, 357
- protonation, 199
- proton conducting fuel cells (PCFCs), 242, 243
- proton conducting membranes, 236
- proton exchange membrane (PEM), 240
- proton exchange membrane fuel cell (PEMFC), 240–245

- pugging, 39, 40  
pulsed electric field (PEF), 309
- r**
- racks, 15  
Raman shifts, 189  
Raman spectroscopy, 150, 188  
random walk model, 130  
redox-tunable membrane, 263  
reduction, 63, 74, 285, 290, 306, 319, 325, 375  
Renkin diffusion, 104  
resistance-in-series model, 122, 123, 134, 138  
reverse osmosis, 9, 23, 277, 278  
Reynolds numbers, 103, 114  
rheology, 37  
ring diffusion mechanism, 107  
roughness factor, 196  
Rutherford backscattering spectrometry (RBS), 150, 185
- s**
- Saccharomyces cerevisiae*, 319  
*Salmonella typhimurium*, 311  
salt gradient, 200  
scanning electron microscopy (SEM), 150, 174–176  
Schmidt number, 113, 121  
Scotch tape test, 195  
sedimentation, 313  
semipermeable active, 1  
sensitivity, 168  
shear stresses, 192  
Shiga toxin-producing *E. coli* (STEC), 305  
Si/Al ratio, 70  
SiC membranes, 284, 363, 379  
sieving, 55  
silicalites, 70, 256  
silicoaluminophosphates (SAPO), 70  
silicon alkoxide, 67  
silicon carbide (SiC), 271, 291, 363  
silver catalyst nanoparticles, 257  
sintering, 12, 46, 47, 50, 51, 189, 190, 195  
skids, 15  
slipcasting, 41  
slurry mixing techniques, 40  
SOFCs. *see* solid oxide fuel cells (SOFCs)  
sol-gel-coated ceramic membranes, 69  
sol-gel technology, 1, 55, 66–69, 257, 261  
solid-liquid thermoporometry, 150, 162–164  
solid oxide fuel cells (SOFCs), 155, 236, 245, 247  
solid-vapour interface, 48  
solute rejection tests, 165–169  
solute-solute attachment, 19  
solute transport tests, 150  
solvent evaporation, 37  
solvothermal synthesis, 261  
soot-filter regeneration, 382  
specific conductivity, 198  
spiking tests, 169–171  
spiral-wound modules, 16  
Sr<sub>1</sub>Fe<sub>1</sub>-CO<sub>0.5</sub>O<sub>x</sub> tubular membrane reactor, 264  
stacks of tubular alumina membranes, 16  
steady-state conditions, 140  
steam-assisted crystallization, 73  
steric hindrance, 67, 68, 104  
sterilization, 23, 297, 317–319, 321, 323  
Stokes' relation, 103  
streaming potential, 150, 198, 199  
stress-strain and stress-compression diagrams, 193, 194  
strontium cerate (SrCeO<sub>3</sub>), 237  
styrene, 281  
sulfonated tetrafluoroethylene PFSA-class fluoropolymer copolymer, 241  
sulfur-containing compounds, 320  
Sumerians, 320  
supermicropores, 11  
surface charge, 199  
surface diffusion, 46, 91, 125, 128–131  
– of hydrogen, 137  
surface-enhanced Raman spectroscopy (SERS), 188  
surface grinding, 54  
surface tension, 38, 157, 160, 196  
surface wettability, evaluation of, 196  
surfactants, 22, 198  
sweeping gas membrane distillation (SGMD), 276  
SWOT (strengths, weaknesses, opportunities and threats) analysis, 358, 359
- t**
- tangential potential, 199  
tape casting, 41, 42  
Teflon, 69, 254  
temperature-independent pre-exponential term, 102  
tensile/compressive strengths, 193  
tensile strengths, 194  
tensile stress, 192  
tetraethoxysilane (TEOS), 63, 66  
tetramethoxysilane (TMOS), 63, 66  
tetrapropylammonium bromide (TPABr), 72  
tetrapropylammonium hydroxide (TPAOH), 72

- theoretical flow-pressure curve, 156
- thermally decomposed tetraethoxysilane (TEOS), 64
- thermal stability, 32, 73, 241
- thermodynamic equilibrium, 250
- thermogravimetric analysis (TGA), 44
- thermolysis, 45
- thickness, 13, 41, 57, 59, 115, 140, 154, 201
- thin-layer membrane, 260
- three-point bending test, 195
- TiO<sub>2</sub> ceramic membranes, 279
- titania, 33
- toluene, 260
- tortuosity, 191
- total cost of ownership (TCO), 367
- total diffusion coefficient, 101, 102
- total gas permeation rate, 154
- total organic carbon (TOC), 269, 295
- total suspended solids (TSS), 317
- trains, modules assembled in, 15
- transmembrane flux, 91, 170, 198, 278, 297
- transmembrane pores, 152
- transmembrane pressure (TMP), 6, 7, 154, 157
- transmembrane streaming potentials, set-up for, 199
- transmembrane potentials, measurements, 199
- transmission electron microscopy (TEM), 150, 176–178
- triethylamine, 72
- TS-1 nanoparticles, 264
- tubular and plate-and-frame modules, 17, 18, 95
- tubular porous membrane reactor, 262
- turbulent diffusion, 95
- turbulent flow, 114
- u**
- ultrafiltration (UF), 1, 9, 10, 55, 150, 295, 363
- ultramicropores, 11
- uranium isotopes, 3
- v**
- vacuum membrane distillation (VMD), 276
- validity, 154
- vibrational spectroscopy, 185–189
- VINI-TIS module, 324
- vinyl chloride monomer (VCM), 356
- volatile organic compounds (VOCs), 44
- w**
- Wagner equation, 141
- water conflict chronology, 272
- water electrolysis, 239
- WaterGuard tablets, 274
- water quality, 269
- water softening, 70
- water to oil ratio (WOR), 292
- water treatment, 271, 286
- plants, 269, 270, 286, 290
- wet membrane, 157
- wettability, 37, 196
- Wilke–Chang equation, 104
- wine, 321, 325
- and ceramic membranes, 321–326
- clarification, 55, 322, 323, 326
- consumption, 326
- deterioration, 322
- filtration installations, 324
- filtration/sterilization, 323
- lees, 322
- tannins, 324
- wort, 315
- x**
- X-ray diffraction (XRD), 150, 184, 259
- X-ray photoelectron spectroscopy (XPS), 150, 172
- y**
- Young modulus, 193, 195
- equation modification of, 196
- yttrium oxide (Y<sub>2</sub>O<sub>3</sub>), 38
- z**
- zeolites, 55, 70, 198, 282
- coating, 69–73
- membranes, 31, 32, 174, 252, 261, 285, 374
- modifications, 1
- structures, 70
- ZSM-5 membrane, 252, 253, 264
- zero emission cycle, 230
- zeta potential, 198
- zirconia, 29, 33
- membranes, 30

