

Index

- A**
- Abrasion method:
 - regeneration 172
 - rejuvenation 226
 - Abrasives 253–255
 - Advanced refineries 13, 15
 - Albermarle 10, 168
 - Alloys 253–255
 - Alumina 254
 - market and price trends 320
 - Ammonia/ammonium salt solutions
 - for metal extraction 270
 - Arsenic 81
 - deposition 54, 67, 124
 - Arsenic sulphide oxidation 114
 - Asphaltenes:
 - coke deposition and 63, 64
 - reactivity 79
 - solubility 79
 - Asphaltenic bottom conversion (ABC) process 42
 - Atmospheric residue desulfurization (ARDS) process 77
 - cascading 228, 229
 - catalyst reprocessing 232
 - catalysts 54
 - spent catalyst properties 60, 61
 - Attrition method:
 - regeneration 172
 - rejuvenation 226
 - AXENS 33
- B**
- Batelle process 302
 - Belt regeneration process 182–184
 - Bioleaching 285, 288
 - kinetics 287
 - Biorejuvenation 225
 - Brim sites model 25
 - BRIM technology 33
 - Bypassing 10, 11
- C**
- Carbocations 74
 - Carbothermic reduction 302, 303
 - Cascading 227
 - regenerated catalysts 228
 - rejuvenated catalysts 230
 - spent catalyst 228
 - Catalysts 1, 22
 - deactivation of *see* Deactivation
 - demand for 2
 - dewaxing 260, 261
 - improved catalysts 32
 - physical properties 28, 29, 90
 - feed effects 30
 - shapes 32
 - reactions with air 112
 - reactor volume maximization 10, 12
 - structural change of 55
 - structure and chemical composition 23
 - support effects 27, *see also* New catalysts from spent catalysts; Spent catalysts
 - CENTINEL catalysts 33
 - reactivation 168
 - Chevron Research Company 271
 - Chevron RDS process 42
 - Chlorination 297, 300
 - Citric acid reprocessing 244, 245
 - Clean Air Act (CAA) 96
 - Clean Water Act (CWA) 95
 - Co-Mo-C(S) phase 24, 26
 - structural stability 55, 56
 - Co-W-S phase 24
 - CO₂:
 - formation *see* Oxidation; Oxidative regeneration
 - regeneration in 165–167
 - Cobalt market and price trends 319
 - Coke:
 - analysis on spent catalysts 125, 126
 - catalyst deactivation 51–53, 56
 - combined effect of coke and metals 60, 62
 - deposition 57, 58, 59
 - asphaltene and resin effects 63, 64
 - hydrogen pressure effect 70, 71
 - metal effects 65, 66
 - temperature effect 67, 68
 - formation mechanism 73
 - chemical aspects 73, 74
 - NMR analysis 75
 - optical microscopy 78
 - physical aspects 78
 - oxidation 109, 125, 127
 - "hard" and "soft" coke 130
 - removal 121, *see also* Regeneration
 - Comprehensive Environmental Resource, Compensation and Liability Act (CERCLA) 94

- Conventional refinery 7
 revamped conventional refinery 10
- CRI-MET process 183, 311
- Crude oils:
 properties 5, 8
 yields related to quality 13
- Cyanex 272 307, 308
- D**
- De-oiling 102, 214, 216
- Deactivation 2, 51, 52
 by coke and nitrogen bases 56
 combined effect of coke and metals 60, 62
 dewaxing catalysts 263
 experimental conditions and 54
 mechanical properties of catalyst and 71, 72
 mechanisms
 coke formation mechanism 73
 metal deposition mechanism 80
 modeling of 85, 87, 89, 90
 structural change of catalyst 55
- Deasphalted oil (DAO) 9, 19, 20
- Density grading of spent catalyst 178, 180
- Dewaxing 259
 conventional catalysts 260
 dewaxing catalysts composition 261
 deactivation 263
 environment and safety issues 264
 metal reclamation 266
 regeneration 264
- Diffusion controlled kinetics 146, 147
- Disposal of spent catalysts 99
 pretreatment for 116, *see also* Environmental hazards
- Drinking water standards 95
- E**
- Ebullated bed reactors 44
 catalyst handling system 47
- demand for 45
 spent catalyst properties 215
- Electrolytic cells 302, 303
- Encapsulation 117
- Environmental hazards:
 dewaxing catalysts 264
 exposure to air
 catalyst reactions with air 112
 coke reactions with air 109
 leachability 115
 oxidative regeneration 163
 pretreatment of spent catalysts for disposal 116
 rejuvenation processes 212, 224, *see also* Safety issues
- Environmental regulations 3, 14, 52, 321, *see also* Regulatory affairs
- EUROCAT 177
 regeneration process 187, 311
- Extra heavy feeds 99
- EXXON Residfining process 42
- EXXSOL D80 307, 308
- F**
- Feeds
 heavy and extra heavy feeds 99
 light feeds 19
 medium heavy feeds 19
 properties of 17, 18
- Fe(NO₃)₃ + oxalic acid rejuvenation system 199
- Fischer-Tropsch (FT) synthesis 17, 19
- Fixed bed reactors 37–39
 atmospheric residue desulfurization (ARDS) process 43
 catalyst loading method 40
 heavy feeds 41
 HYVAHL process 43
 in series 41
 influence of catalyst properties 40
 Unibon process 42
- Flow distribution 10, 11
- Fluid catalytic cracking (FCC)
 catalyst use in cement industry 250
 oxidative regeneration 146, 147
 modeling 148
- Fuel specifications 5, 7
- Full Yield Industry process 312
- G**
- Gasification 15, 16
- German metal reclamation processes 314
- Ground water monitoring 101
- Guard chamber 37
- Guard reactors 37, 41
- Gulf Chemical and Metallurgical Corporation (GCMC) 254, 255
 metal reclamation process 310
- Gulf RDS process 42
- H**
- H-Oil process 45, 46
- Hazardous Waste Trust Fund (HWTF) 94
- Heavy feeds 99
 fixed bed reactors 41
- HOP catalysts 33
- Hydrochloric acid, metal extraction 276
- Hydrocracking (HCR) 9
 dewaxing 259, 261
 spent catalysts in slurry bed hydrocracking 246
- Hydrodearomatization (HDAR) 21
- Hydrodeasphaltization (HDA) 21, 82
- Hydrodemetallization (HDM) 21
 reprocessed catalyst testing 236, *see also specific metals*
- Hydrodenickelization (HDNi) 82
- Hydrodenitrogenation (HDN) 21
- Hydrodeoxygenation (HDO) 21
- Hydrodesulfurization (HDS) 21
 catalyst properties and 29, 31, 34, 40
 feed origin influence 31
 modes of promotor addition effects 200
 reprocessed catalyst testing 236, 243
 hydrothermal treatment effect 244

- Hydrodevanadization (HDV) *see*
Vanadium
- Hydrogen pressure:
catalyst deactivation
relationships 52
coke deposition and 70, 71
hydrogen consumption
correlation 17, 18
- Hydrogenation (HYD) 9, 21
- Hydroisomerization (HIS) 9, 21
dewaxing 259, 261
- Hydromet Corporation
immobilization process 119
- Hydroprocessing
catalysts 22
improved catalysts 32,
33
physical properties 28,
29
spent catalyst
regenerability 121
structure and chemical
composition 23
feeds for heavy and extra
heavy feeds 99
light feeds 19
medium heavy feeds 19
properties of 17, 18
reactions 21
reactors and processes 35
comparison of reactors
48, 49
fixed bed reactors systems
38, 39
moving bed and ebullated
bed reactors 44, 47
operating conditions 36
severity 17
- Hydrothermal treatment,
reprocessed catalysts 242–244
- HYVAHL process 41, 43
cascading 228, 229
- I**
- In-situ regeneration 173, 174, 175
- Industrial regeneration *see*
Regeneration
- Inorganic solids 80
- Inter-stage gas treatment 11–13
- Iron deposition 65
- Isothermal oxidation 111
- K**
- Kashima Engineering Co. 102
- KISR 193, 194
- Kuwait Catalyst Company 33
- L**
- Landfill 100, 101, 323
pretreatment of spent catalysts
for disposal 116, *see also*
Environmental hazards;
Environmental
regulations
- LC-Fining process 45, 46
- Leachability 115
pretreatment of spent catalysts
for disposal 116
- Leaching 217, 270, 305
acid leaching 273, 282
inorganic acids 273, 274,
275, 278, 279
organic acids 277, 281
alkali leaching 281, 284
bioleaching 285, 288
kinetics 287
two-stage leaching 283
with ammonia and ammonium
salt solutions 270, *see also*
Leachability; Metal
reclamation;
Rejuvenation
- Light feeds 19
- LIX 63 307, 308
- M**
- Maectite process 118
- Magnetic separation 226
- Markets:
alumina 320
cobalt 319
molybdenum 317
nickel 318
tungsten 318
vanadium 319
- Mechanical separation:
regeneration processes
178–182
rejuvenation processes 214,
216
- Medium heavy feeds 19
- Membrane separation 309
- Metal reclamation 269
commercial processes 309
dewaxing catalysts 266
flow sheet 291
future trends 322
laboratory studies 269, 304
carbothermic reduction
302, 303
chlorination 297, 300
electrolytic cells 302, 303
extracting agents 270, 271
leaching studies 270, 305
roasting with alkali
compounds 289, 305
thermal plasma 303
separation from solution
306–308
- Metallurg Vanadium process 314
- Metals:
catalyst deactivation 52, 53,
61, 84
combined effect of coke
and metals 60, 62
deposition mechanism 81
deposits of
organometallic
origin 81
inorganic solids 80
hazardous constituents of spent
catalysts 105, 107
immobilization 117–119
involvement in oxidative
regeneration 134
markets and price trends 317
alumina 320
cobalt 319
molybdenum 317
nickel 318
tungsten 318
vanadium 319, *see also*
Metal reclamation;
Rejuvenation
- METREX process 309
- Modeling:
catalyst deactivation 85, 87,
89, 90
oxidative regeneration 148
- Molybdenum:
markets and price trends 317
molybdenum sulphide
oxidation 112, 136

- reprocessed catalysts 236, 238, 240, 241, 245, *see also* Metal reclamation; Metals
- Moving bed reactors 44
- Moxba-Metrex process 313
- N**
- N-compounds, catalyst deactivation 51, 56
poisoning effect 57
- National Primary Drinking Water Standards (NPDWS) 95
- National Secondary Drinking Water Standards (NSDWS) 95
- NEBULA 33, 34
- New catalysts from spent catalysts 231
gas treatment sorbents 248–251
new catalyst production from spent catalysts, spent catalysts in slurry bed hydrocracking 246
non-petroleum applications 247
petroleum applications 231
reprocessing 232, 233
spent catalysts in slurry bed hydrocracking 246
- Ni-Mo-S phase 24
structural stability 56
- Ni-W-S phase 24
- Nickel:
deposition 65
mechanism 83
market and price trends 318
oxidation 134
porphyrins 81–83
removal:
organic agents 195, 198, 203, 204
acidic agents 221, 222
basic solutions 223
microorganism-aided removal 225
reprocessed catalyst testing 238
stability of oxalic acid complexes 205, *see also* Metal reclamation; Metals
- Nickel sulphide oxidation 112, 113
- Nippon Catalyst Cycle Co. Ltd (NCC) process 315
- O**
- Off-site regeneration 173, 174, 176
- Oxalic acid:
catalyst rejuvenation 194, 195
additive effects 195, 198
coked catalyst 206
Fe(NO₃)₃ + oxalic acid system 199
mechanisms 201, 204
catalyst reprocessing 244, 245
metal extraction 277
stability of metal complexes 205
- Oxidative regeneration 125
characterization of regenerated catalysts 149, 150
activity 154, 156, 157
chemical structure 158, 160
surface properties 150, 152, 153, 154
temperature effects 150–152, 155
kinetics 140
chemically controlled kinetics 141
diffusion controlled kinetics 146, 147
mechanism 125
coke oxidation 125, 127
metal involvement 134
modeling of 148
ignition temperature prediction 148, 149
other oxidizing agents 164, 165
safety and environmental aspects 160
- Ozone oxidation 164, 165
- P**
- Paraffins 259, *see also* Dewaxing
- Particle scale models 86
- PC-88A 308
- Percolation model 89
- Petroleum refining 5, 8
advanced refineries 13, 15
conventional refinery 7
revamped conventional refinery 10
future trends 321, 322
new catalyst production from spent catalysts 231
reprocessing 232
- Phoenix Environmental thermal treatment process 117
- PIA-8 308
- Poisoning effect 51
N-compounds 57
- Porocel 177
belt regeneration process 182–184
- Porphyrins 82
nickel 81–83
vanadium 81–83
- Potassium salts, roasting with 295, 297, 298
- Presulfiding method 172
- Price trends:
alumina 320
cobalt 319
molybdenum 318
nickel 318
tungsten 318
vanadium 319
- Q**
- Quanzhou Jing-Tai Industry Co. process 314
- R**
- REACT technology 168, 177, 188
- Reactivation 168, 169
- Reactors 35, 36
fixed bed reactors 37–39
operating conditions 36
shutdown procedure 102, 104
- Recycling of spent catalysts:
regulatory issues 99
- Reductive regeneration 170, 171
- ReFRESH process 188, 189
- Regeneration 121
by attrition/abrasion 172
cascading of regenerated catalysts 228
comparison of processes 189
dewaxing catalysts 264
future trends 270, 323
in H₂O and CO₂ 165–167

- in nitrogen oxides 167
 - industrial regeneration 173
 - commercial regeneration processes 182
 - in-situ regeneration 173, 174, 175
 - mechanical separation of spent catalyst 178–182
 - off-site regeneration 173, 174, 176
 - oxidative regeneration 125
 - characterization of regenerated catalysts 149
 - kinetics 140
 - mechanism 125
 - modeling of 148
 - other oxidizing agents 164, 165
 - oxidation of catalyst 112
 - oxidation of coke 109, 125
 - oxidation of metals 134
 - safety and environmental aspects 160
 - radiation treatment 169
 - reactivation 168, 169
 - reductive regeneration 170, 171
 - regenerability of spent catalysts 121, 265
 - resulfidation of regenerated catalysts 172
 - Regulatory affairs 94
 - handling spent catalyst on refinery site 101
 - spent catalyst classification 96
 - spent catalyst recycling and disposal 99
 - spent catalyst transportation 97, *see also* Environmental regulations
 - Rejuvenation 192
 - biorejuvenation 225
 - cascading of rejuvenated catalysts 230
 - effects on catalyst 196
 - emissions from 212
 - gaseous emissions 213
 - liquid emissions 213
 - solid emissions 214
 - future trends 322
 - inorganic agents
 - acidic agents 219
 - basic solutions 222
 - environmental and safety aspects 224
 - kinetics 207
 - particle changing size model 208, 212
 - particle constant size 207
 - non-leaching methods 226
 - organic agents 193, 201, 203
 - coked catalyst 206–208
 - equilibrium constants 202
 - mechanisms 201
 - structures of 201
 - process design 214, 218
 - auxillary processes 217
 - de-oiling 214, 216
 - decoking of leached catalyst 217
 - design basis 217
 - mass balance 219
 - mechanical separation 214, 216
 - metals leaching process 217
 - solvent extraction 224
 - strategy 191, 192
 - Reprocessing 232
 - alternative preparation methods 244
 - hydrothermal treatment effect 242–244
 - procedure and analysis 232, 233
 - spent catalyst content effect 234–237, 239
 - testing of reprocessed catalysts 236
 - Resource Conservation and Recovery Act (RCRA) 94
 - Resulfidation of regenerated catalysts 172
 - Revamped conventional refineries 10
 - Roasting with alkali compounds 289, 305
 - potassium salts 295, 297, 298
 - sodium salts 290, 292–296
 - Rotary kilns 188
- ## S
- Safania vacuum residue 48
 - Safe Drinking Water Act (SDWA) 95
 - Safety issues 49
 - dewaxing catalysts 264
 - hazardous characteristics of spent catalysts 105, 108
 - exposure to air 109
 - hazardous constituents 107
 - leachability 115
 - oxidative regeneration 160
 - rejuvenation processes 224, *see also* Environmental hazards; Regulatory affairs
 - Shell 10
 - Shutdown procedure 102, 104
 - Single pellet model 87
 - Skin removal 220
 - Slurry bed reactors 246
 - spent catalysts in hydrocracking 246
 - SMART catalyst system 34
 - SO₂ formation *see* Oxidation; Oxidative regeneration
 - Sodium salts, roasting with 290, 292–296
 - Solvent extraction 224, 306–308
 - Spent catalysts 4
 - cascading 228
 - compounds recovered from 270
 - conventional refineries 9
 - decision making regarding fate 103
 - disposal of 3, 4
 - pretreatment for 116
 - generation of 2
 - future trends 321
 - handling of 93
 - on refinery site 101

- hazardous characteristics of
105, 108
exposure to air 109
hazardous constituents
107
leachability 115
management approach 105,
106
metal reclamation from *see*
Metals
properties of 215, 232
regenerability of 121, *see also*
Regeneration
regulatory issues:
classification 96
recycling and disposal 99
transportation 97
rejuvenation of *see*
Rejuvenation
slurry bed hydrocracking 246
storage 104
useful materials from 251
abrasives and alloys
253–255
bricks production 256
cement industry 250
ceramic materials 254,
255
gas treatment sorbents
248–251
synthetic aggregates 256,
257
waste water treatment
agents 252, *see also*
New catalysts from
spent catalysts~
- Sulfuric acid, metal extraction
273
Superfund 94
SYNEX DN-052 307, 308
Synthetic aggregates 256, 257
- T**
- Taiyo Koko Company process 312,
313
- Temperature:
catalyst deactivation
relationships 52
coke deposition and 67, 68
regeneration temperature
effects 150–152, 155
temperature runaway on air
introduction to spent
catalyst 160
Temperature programmed oxidation
(TPO) 109, 110, 130
CO₂ yields 128
nitrogen conversion 132, 133
SO₂ formation 135
time on stream effect 131
Temperature programmed pyrolysis
(TPP) 138
Tetrahydrofluran insolubles
(THFIS) 75–77
Thermal gravimetric analysis
(TGA) 144, 145
Thermal plasma 303
THERMIDOR model 91, 92
Toluene insolubles (TIS) 75–77
Toxic Substance Control Act
(TSCA) 94
Toxicity Characteristics Leaching
Procedure (TCLP) 115, 118
TR-83 308
Transportation:
emissions 321
fuel demand 5, 6
of spent catalysts 97, 104
Transportation of Dangerous
GOODS (TDG) 97
TRICAT 173, 177
regeneration process (TRP)
185, 186
Trickle bed reactors 38
Tungsten market and price trends
318
- U**
- Ultimate storage capacity 87
UltraMix 10
- Unibon process 42
Unicracking process 39, 42
Universal Oil Products (UOP) 10
Unloading procedure 102, 103
Upflow reactors 38
- V**
- Vacuum distillation 7
Vacuum gas oil (VGO) 7, 19
spent catalyst regeneration
122, 124
Vacuum residue (VR) 19
spent catalyst regenerability
123
Vanadium:
deposition 65, 66
market and price trends 319
oxidation 134
porphyrins 81–83
removal:
acidic agents 221, 222
basic solutions 223
coked catalyst 206, 207
effects on catalyst 196
kinetics 209, 210
microorganism-aided
removal 225
organic agents 194, 195,
197, 199, 203
reprocessed catalyst
testing 236, 243, 244
stability of oxalic acid
complexes 205
reprocessed catalysts 238, 239,
242
vanadium containing deposits
81, *see also* Metal
reclamation; Metals
- W**
- Waste water treatment agents 252
Wastes 93, *see also* Spent catalysts
- Z**
- Zeolites 262