

# Contents

Preface	9
List of contributors	11
Abstracts	13
Contents	17
<b>Chapter 1. Sorption processes and pollution: An introduction</b>	
Grégorio CRINI and Pierre-Marie BADOT	27
<b>Introduction</b>	27
<b>Water pollution</b>	28
Different types of effluent	28
The variability of pollution	28
<b>Wastewater treatment</b>	30
General scheme of wastewater treatment	30
Technologies available for pollutant removal	31
<b>Sorption processes</b>	34
Activated carbon sorption	34
Non-conventional sorbent materials	35
<b>Conclusions</b>	36
<b>References</b>	37
<b>Chapter 2. Wastewater treatment by sorption</b>	
Grégorio CRINI	39
<b>Introduction</b>	39
<b>Pollutants as sorbates</b>	40
<b>Sorption processes</b>	42
Definitions	42

Batch methods	44
Sorbent materials	45
Characterization of sorbents	46
Types of sorbent material for pollutant removal	49
<b>Control sorbent performance</b>	55
Influence of the solid characteristics	55
Surface chemistry of the sorbent	55
Activation conditions	56
Effect of operating variables	56
Effect of the solution conditions	57
Chemistry of the pollutant	58
Sorbent regeneration – desorption of pollutants	58
The mechanisms of sorption/adsorption/biosorption	59
Modeling	61
Freundlich and langmuir sorption isotherms	63
Error functions	65
Kinetics	66
Thermodynamic studies	71
<b>Conclusions</b>	72
<b>References</b>	73
<b>Chapter 3. Fixed-bed adsorption studies</b>	
Adriana S. FRANCA and Leandro S. OLIVEIRA	79
<b>Introduction</b>	79
Determination and prediction of breakthrough curves	81
Bohart and Adams model (BDST)	84
Clark model	85
Thomas model	86
Yoon and Nelson model	87
Wolborska model	87
Modified BDST model	88
Dose-response model	89
Constant pattern wave model	90
Mass transfer theory-based models	91
<b>Applications in pollutant removal</b>	94
<b>Concluding remarks</b>	105
<b>Acknowledgements</b>	106
<b>References</b>	106
<b>Chapter 4. Adsorption of phenolic compounds on activated carbons</b>	
Mariusz BARCZAK and Andrzej DAŁBROWSKI	113
<b>Introduction</b>	113

---

<b>Activated carbon as the basic adsorbent for uptake of phenols</b>	117
Precursors of activated carbons	117
Surface chemistry of activated carbon	120
<b>Adsorption of phenols on activated carbon</b>	121
Role of the surface heterogeneity in the adsorption of phenols	121
Role of the porous structure on the adsorption of phenols	124
<b>Irreversible adsorption of phenols</b>	125
<b>Concluding remarks</b>	127
<b>Acknowledgements</b>	127
<b>References</b>	127
<b>Chapter 5. Influence of thermal and chemical treatments on activated carbon characteristics, and effects on adsorption performance with respect to dyes, emerging contaminants and humic acids</b>	
Sarra GASPARD, Marie-Julie PINTOR, Axelle DURIMEL and Valérie JEANNE-ROSE	131
<b>Introduction</b>	131
<b>Elaboration of activated charcoals</b>	132
Elaboration by physical activation	134
Chemical activation	136
Influence of activation method	138
<b>Methods and tests for activated carbon characterization</b>	139
Usual methods	140
Original methods	147
<b>Dyes adsorption</b>	148
Isotherm models	148
Dyes removal	149
<b>Emerging contaminants and pesticides adsorption</b>	154
Humic substances	157
<b>Concluding remarks</b>	160
<b>Acknowledgments</b>	160
<b>References</b>	160
<b>Chapter 6. Silicas adsorbents for pollutants removal</b>	
Sławomir BINKOWSKI	167
<b>Introduction</b>	167
<b>Characteristics of silica</b>	168
Classification	168
Surface chemistry	169
<b>Modification of the silica surface</b>	171

Modifying agents	171
Silane proadhesion compounds	171
Methods of modification	172
<b>Adsorption of pollutants</b>	<b>175</b>
Types of pollutants	175
Adsorption of various pollutants on silica adsorbents	176
<b>Conclusions</b>	<b>183</b>
<b>Acknowledgments</b>	<b>184</b>
<b>References</b>	<b>184</b>
<b>Chapter 7. Non-conventional sorbents for dye removal</b>	
François RENAULT, Nadia MORIN-CRINI, Pierre-Marie BADOT and Grégorio CRINI	187
<b>General</b>	<b>187</b>
<b>Dye molecules</b>	<b>188</b>
<b>Langmuir equation</b>	<b>188</b>
<b>Non-conventional sorbents for dye removal</b>	<b>189</b>
Activated carbons from solid wastes	189
Clays	191
Siliceous materials	192
Zeolites	194
Agricultural solid wastes	194
Industrial by-products	196
Peat	197
Chitin and chitosan	198
Biomass	200
Starch-based derivatives	202
Miscellaneous sorbents	203
<b>Concluding remarks</b>	<b>204</b>
<b>Acknowledgements</b>	<b>205</b>
<b>References</b>	<b>205</b>
<b>Chapter 8. Kaolin as an adsorbent for color removal</b>	
Aparajita GOSWAMI and Mihir Kumar PURKAIT	215
<b>Introduction</b>	<b>215</b>
<b>Techniques used for color removal from wastewater</b>	<b>217</b>
Physical techniques	217
Chemical techniques	218
Biological treatment	218
<b>Different adsorbents used for treating colored water</b>	<b>218</b>
Kaolinite as an adsorbent for dye removal	219

---

Structure of kaolinite	220
Properties	220
How kaolinite adsorbed dye molecules	221
Modification of kaolin surface	221
<b>Discussion</b>	222
Dye adsorption kinetics	222
Adsorption kinetic modeling and mechanism	226
Regeneration of adsorbent	229
<b>Concluding remarks</b>	230
<b>References</b>	230
<b>Chapter 9. Wood sawdust, tree bark and wood chips: Waste lignocellulosic materials for dye removal</b>	
Viorica DULMAN and Simona-Maria CUCU-MAN	233
<b>Introduction</b>	233
<b>Preparation and characterization of wood-derived lignocellulosic adsorbents</b>	234
Preparation of adsorbents	234
Characterization of adsorbents	235
<b>Adsorption mechanism</b>	238
<b>Factors affecting the batch adsorption of dyes on wood-derived lignocellulosic adsorbents</b>	240
Effect of pH	240
Effect of initial dye concentration and contact time	243
Effect of chemical treatment of adsorbent	245
Effect of particle size	246
Effect of adsorbent dose	247
Effect of salts and surfactants	248
Effect of agitation rate	248
Effect of temperature	248
<b>Adsorption equilibrium</b>	250
<b>Adsorption kinetic models</b>	254
Pseudo-first order model	254
Pseudo-second order model	255
Diffusion processes	257
Other kinetic models	260
Thermodynamic studies	260
<b>Column studies</b>	263
<b>Concluding remarks</b>	266
<b>References</b>	267

<b>Chapter 10. Polysaccharides for metal ion recovery – A focus on chitosan</b>	
Jacques DESBRIERES and Eric GUIBAL	271
<b>Introduction</b>	271
<b>Sorption mechanisms on chitosan</b>	273
Physico-chemistry of chitosan complexation	273
Electrostatic attraction and ion exchange mechanisms	276
<b>Controlling parameters</b>	278
Crystallinity and swelling behavior	278
Diffusion properties	279
Metal speciation properties	281
<b>Modes of application</b>	284
Chitosan in solution	285
Chitosan in batch/column	285
Specific conditionings	286
<b>Example: application to recovery of metals from tannery waters in Morocco</b>	287
<b>Chitosan and metal ions for the design of new materials</b>	288
Environmental applications	288
Analytical applications	288
Biological and biomedical applications	289
Catalytic applications	290
Biosensor and microdevices applications	291
Miscellaneous applications	292
<b>Conclusions and perspectives</b>	292
<b>References</b>	293
<b>Chapter 11. Non-conventional adsorbents for the removal of metal compounds from wastewaters</b>	
Fabio MONTAGNARO and Luciano SANTORO	297
<b>Introduction</b>	297
<b>Use of non-conventional adsorbents: materials nature and properties, and beneficiation treatments</b>	299
Coal combustion ash and other industrial residues	299
Natural materials, agricultural by-products and other biomasses	301
<b>Adsorption of metals on non-conventional adsorbents</b>	302
Specific adsorption capacity	302
Langmuir isotherm and thermodynamic parameters	304
Kinetic parameters	305
Controlling mechanisms	308
<b>Concluding remarks</b>	309

Acknowledgements	310
References	311
<b>Chapter 12. Pollutant removal from surface-treatment industry wastewaters by starch-based sorbents: Chemical abatement and impact on water toxicity</b>	
Jérémie CHARLES, Bertrand SANCEY, Giuseppe TRUNFIO, Pierre-Marie BADOT, Michel De CARVALHO, Albert COLIN, Michaël RIETMANN, Jean-François MINARY, Emmanuel GROSJEAN and Grégorio CRINI	313
<b>Introduction</b>	313
<b>Legislation for the control of discharge to the aquatic environment</b>	314
<b>Pollution produced by surface-industries</b>	316
Different types of pollutants	317
The variability of pollution	318
<b>Technologies available for pollutant removal from surface-finishing industry wastewater</b>	320
Chemical precipitation	321
Other methods	323
<b>Separation, recovery and sorption processes</b>	324
Ion-exchange resins	324
Activated carbon adsorption	324
Adsorption using other materials	325
Biosorption of heavy metals	326
Starch-based materials	327
<b>Chemical abatement and impact on water toxicity</b>	327
<b>Closing comments</b>	331
<b>Acknowledgements</b>	331
<b>References</b>	331
<b>Chapter 13. Defluoridation of water and wastewater using non-conventional sorbents</b>	
Giuseppe TRUNFIO, Bertrand SANCEY, Xavier HUTINET and Grégorio CRINI	335
<b>Defluoridation of water/wastewater</b>	335
Fluoride	335
Conventional treatments	336
<b>Sorbents for fluoride removal</b>	340
Activated alumina and alumina-based sorbents	340
Carbon and carbon-based sorbents	343
Rare earth elements	343
Soils	344
Clays	344
Calcium	346
Zeolites	346

Hydroxide-based materials	346
Layered double hydroxides	347
Synthetic resins	348
Industrial by-products	348
Miscellaneous sorbents	349
Biopolymers	349
Chitosan and chitosan derivatives	350
<b>Conclusion</b>	352
<b>Acknowledgements</b>	354
<b>References</b>	354
<b>Chapter 14. Fungal biomasses: non conventional biosorbents for organic and inorganic pollutants</b>	
Valeria TIGINI, Valeria PRIGIONE, Ilaria DONELLI, Antonella ANASTASI, Francesca ISELLA, Giuliano FREDDI and Giovanna Cristina VARESE	359
<b>Introduction</b>	359
Biosorption as an important tool in water decontamination	359
Classification and characteristics of fungi	361
Fungal cell structure and composition with special reference to cell wall	362
<b>Fungal biosorbents towards organic and inorganic pollutants</b>	363
Inorganic pollutants	363
Organic pollutants	364
Biotic parameters affecting fungal biosorption	366
Abiotic parameters affecting biosorption	369
Mechanisms and functional groups related to fungal biosorption	374
Analytical techniques useful in biosorption studies	375
Application of fungal biosorbents to real wastewaters	378
Future in fungal biosorbents	381
<b>Acknowledgements</b>	382
<b>References</b>	382
<b>Chapter 15. Cross-linked cyclodextrins for pollutant removal</b>	385
Bertrand SANCEY, Grégorio CRINI, Giuseppe TRUNFIO, Nadia MORIN-CRINI and Giangiacomo TORRI	385
<b>General</b>	385
<b>Synthesis of cross-linked cyclodextrin-based sorbents</b>	387
Materials modified by epichlorohydrin	388
Other materials prepared by direct cross-linking of cyclodextrin	390
<b>Cross-linked cyclodextrins for pollutant removal</b>	392
A recent review of the literature	392
Sorption mechanism	395
<b>Conclusions</b>	396



---

Acknowledgements	396
References	397
<b>Chapter 16. Calixarene based materials for cations and anions</b>	
Mustafa YILMAZ, Abdulkadir SIRIT and Hasalettin DELIGOZ	401
<b>Introduction</b>	401
<b>Calixarene-based materials for cations</b>	403
Calixarene-based materials for alkali and alkaline earth metals	404
<b>Calixarene-based materials for heavy metal ions</b>	408
Calixarene-based materials for toxic anions	413
<b>Acknowledgements</b>	416
<b>References</b>	417
<b>Chapter 17. Recent advances in porosinit-based nanocomposite adsorbents for pollutants removal from waters</b>	
Bingcai PAN, Xiaolin ZHANG, Weiming ZHANG, Lu LV and Quanxing ZHANG	421
<b>Introduction</b>	421
<b>Nano-metal/metallic compounds and their composite adsorbents</b>	422
Iron and iron (hydr)oxide	423
<b>Carbonaceous nanomaterials and their composites</b>	429
<b>Nano-polysaccharides and their composites</b>	431
<b>Conclusion</b>	432
<b>References</b>	432
<b>Chapter 18. Molecularly imprinted polymers (mips) as selective sorbents for wastewater pollutants</b>	
George Z. KYZAS and Nikolaos K. LAZARIDIS	441
<b>Introduction</b>	441
<b>Preparation of MIPs</b>	443
Selectivity	444
<b>MIPs as sorbents for wastewater pollutants</b>	445
Dyes	445
Ions	446
Herbicides	449
Phenols	451
Pharmaceuticals/drugs	452
<b>Conclusions and perspectives</b>	453
<b>References</b>	453

## Chapter 19. Nanoparticles for pollutants removal

Yousef HAIK and Shahnaz QADRI	459
<b>Introduction</b>	459
<b>Synthesis of nanoparticles</b>	461
Synthesis of carbon nanotubes	461
Synthesis of magnetic nanoparticles	462
Borohydride reduction	463
Chemical co-precipitation method	463
Refluxing in polyol method	464
Encapsulating the magnetic nanoparticles	465
Solvent displacement method	465
Salting out technique	465
Emulsion diffusion method	466
Solvent evaporation method	466
Polymer emulsion process	466
Magnetic separation	467
<b>Adsorption models</b>	468
<b>Sorption example</b>	469
Dye removal by use of magnetic nanoparticles	469
Preparation of magnetic nanoparticles	469
Characterization of magnetic nanoparticles	470
Dye solution	471
Equilibrium studies	472
Dye recovery	474
Dye removal by use of carbon nanotubes	475
Comparison between magnetic nanoparticles and carbon nanotubes	477
<b>Nanotoxicity</b>	477
<b>Concluding remarks</b>	478
<b>References</b>	478
<b>Biography and address of contributors</b>	481
<b>Key-words</b>	491
<b>Nomenclature</b>	493
Greek Letters	495
Notation	495