

Contents

Preface to the second edition — V

Preface to the first edition — VII

1 Introduction — 1

- 1.1 Basic concepts and definitions — 1**
 - 1.1.1 Adsorption as a surface process — 1**
 - 1.1.2 Some general thermodynamic considerations — 2**
 - 1.1.3 Adsorption versus absorption — 3**
 - 1.1.4 Mathematical description of adsorption processes:
The structure of the adsorption theory — 3**
- 1.2 Engineered adsorption processes in water treatment — 5**
 - 1.2.1 Overview — 5**
 - 1.2.2 Drinking water treatment — 6**
 - 1.2.3 Wastewater treatment — 8**
 - 1.2.4 Hybrid processes in water treatment — 11**
- 1.3 Natural sorption processes in water treatment — 12**

2 Adsorbents and adsorbent characterization — 14

- 2.1 Introduction and adsorbent classification — 14**
- 2.2 Engineered adsorbents — 15**
 - 2.2.1 Activated carbons — 15**
 - 2.2.2 Polymeric adsorbents — 18**
 - 2.2.3 Oxidic adsorbents — 20**
 - 2.2.4 Synthetic zeolites — 21**
- 2.3 Natural and low-cost adsorbents — 22**
- 2.4 Geosorbents in environmental compartments — 23**
- 2.5 Adsorbent characterization — 24**
 - 2.5.1 Densities — 24**
 - 2.5.2 Porosities — 26**
 - 2.5.3 External surface area — 28**
 - 2.5.4 Internal surface area — 30**
 - 2.5.5 Pore-size distribution — 32**
 - 2.5.6 Surface chemistry — 39**
- 2.6 Practice-oriented test methods for assessing the performance of
adsorbents — 48**

3	Adsorption equilibrium I: General aspects and single-solute adsorption — 49
3.1	Introduction — 49
3.2	Experimental determination of equilibrium data — 50
3.2.1	Basics — 50
3.2.2	Practical aspects of isotherm determination — 54
3.3	Isotherm equations for single-solute adsorption — 56
3.3.1	Classification of single-solute isotherm equations — 56
3.3.2	Irreversible isotherm and one-parameter isotherm — 56
3.3.3	Two-parameter isotherms — 58
3.3.4	Three-parameter isotherms — 64
3.3.5	Isotherm equations with more than three parameters — 66
3.4	Prediction of isotherms — 68
3.5	Temperature dependence of adsorption — 74
3.6	Slurry adsorber design — 78
3.6.1	General aspects — 78
3.6.2	Single-stage adsorption — 80
3.6.3	Two-stage adsorption — 83
3.7	Application of isotherm data in kinetic or breakthrough curve models — 86
4	Adsorption equilibrium II: Multisolute adsorption — 89
4.1	Introduction — 89
4.2	Experimental determination of equilibrium data — 91
4.3	Overview of existing multisolute adsorption models — 92
4.4	Multisolute isotherm equations — 93
4.5	The ideal adsorbed solution theory (IAST) — 96
4.5.1	Basics of the IAST — 96
4.5.2	Solution to the IAST for given equilibrium concentrations — 100
4.5.3	Solution to the IAST for given initial concentrations — 103
4.5.4	Solution to the IAST for the special case of linear single-solute isotherms — 106
4.6	The pH dependence of adsorption: A special case of competitive adsorption — 107
4.7	Adsorption of background dissolved organic matter (DOM) — 112
4.7.1	The significance of DOM in activated carbon adsorption — 112
4.7.2	Modeling of DOM adsorption: The fictive component approach (adsorption analysis) — 114
4.7.3	Competitive adsorption of micropollutants and DOM — 118
4.8	Slurry adsorber design for multisolute adsorption — 126
4.8.1	Basics — 126
4.8.2	DOM adsorption — 127

4.8.3	Competitive adsorption of micropollutants and DOM —	128
4.8.4	Nonequilibrium adsorption in slurry reactors —	134
4.9	Special applications of the fictive component approach —	137

5 Adsorption kinetics — 140

5.1	Introduction —	140
5.2	Mass transfer mechanisms —	140
5.3	Experimental determination of kinetic curves —	141
5.4	Mass transfer models —	144
5.4.1	General considerations —	144
5.4.2	Film diffusion —	146
5.4.3	Surface diffusion —	153
5.4.4	Pore diffusion —	160
5.4.5	Combined surface and pore diffusion —	166
5.4.6	Simplified intraparticle diffusion model (LDF model) —	170
5.4.7	Reaction kinetic models —	179
5.4.8	Adsorption kinetics in multicomponent systems —	182
5.5	Practical aspects: Slurry adsorber design —	184

6 Adsorption dynamics in fixed-bed adsorbers — 187

6.1	Introduction —	187
6.2	Experimental determination of breakthrough curves —	193
6.3	Fixed-bed process parameters —	194
6.4	Material balances —	197
6.4.1	Types of material balances —	197
6.4.2	Integral material balance —	198
6.4.3	Differential material balance —	204
6.5	Practical aspects —	209
6.5.1	Introduction —	209
6.5.2	Typical operating conditions —	209
6.5.3	Fixed-bed versus batch adsorber —	211
6.5.4	Multiple adsorber systems —	212

7 Fixed-bed adsorber design — 215

7.1	Introduction and model classification —	215
7.2	Scale-up methods —	216
7.2.1	Mass transfer zone model —	216
7.2.2	Length of unused bed model —	220
7.2.3	Rapid small-scale column test —	222
7.3	Equilibrium column model —	227
7.4	Complete breakthrough curve models —	231
7.4.1	Introduction —	231

7.4.2	Homogeneous surface diffusion model —	234
7.4.3	Constant pattern approach to the HSDM —	237
7.4.4	Linear driving force model —	241
7.4.5	Comparison of HSDM and LDF model —	245
7.4.6	Simplified breakthrough curve models with analytical solutions —	248
7.5	Determination of model parameters —	254
7.5.1	General considerations —	254
7.5.2	Single-solute adsorption —	255
7.5.3	Competitive adsorption in defined multisolute systems —	260
7.5.4	Competitive adsorption in complex systems of unknown composition —	260
7.6	Special applications of breakthrough curve models —	262
7.6.1	Micropollutant adsorption in the presence of background organic matter —	262
7.6.2	Biologically active carbon filters —	270
8	Desorption and reactivation —	275
8.1	Introduction —	275
8.2	Physicochemical regeneration processes —	276
8.2.1	Desorption into the gas phase —	276
8.2.2	Desorption into the liquid phase —	278
8.3	Reactivation —	285
9	Geosorption processes in water treatment —	288
9.1	Introduction —	288
9.2	Experimental determination of geosorption data —	290
9.3	The advection-dispersion equation and the retardation concept —	292
9.4	Determination of the retardation factor from experimental breakthrough curves —	294
9.5	Breakthrough curve modeling —	297
9.5.1	Introduction and model classification —	297
9.5.2	Local equilibrium model —	298
9.5.3	Linear driving force model —	301
9.5.4	Extension of the local equilibrium model —	303
9.6	Combined sorption and biodegradation —	305
9.6.1	General model approach —	305
9.6.2	Special case: Sorption and biodegradation of dissolved organic matter —	310
9.7	The influence of pH and DOM on geosorption processes —	312
9.7.1	pH-dependent sorption —	312

9.7.2	Influence of DOM on micropollutant sorption —	314
9.8	Practical aspects: Prediction of subsurface solute transport —	316
9.8.1	General considerations —	316
9.8.2	Prediction of sorption coefficients —	318
9.8.3	Prediction of the dispersivity —	320

10 Appendix — 321

10.1	Conversion of Freundlich coefficients —	321
10.2	Alternative solution equations of the ideal adsorbed solution theory —	322
10.3	Theoretical basics of the simplified equivalent background compound model —	323
10.4	Evaluation of surface diffusion coefficients from experimental data —	326
10.5	Constant pattern solution to the homogeneous surface diffusion model —	331
10.6	Viscosity of water —	335

Nomenclature — 337

References — 349

Index — 357