

Green Chemistry and Sustainable Technology

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The series *Green Chemistry and Sustainable Technology* aims to present cutting-edge research and important advances in green chemistry, green chemical engineering and sustainable industrial technology. The scope of coverage includes (but is not limited to):

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- Green technologies for environmental sustainability (carbon dioxide capture, waste and harmful chemicals treatment, pollution prevention, environmental redemption etc.)

The series *Green Chemistry and Sustainable Technology* is intended to provide an accessible reference resource for postgraduate students, academic researchers and industrial professionals who are interested in green chemistry and technologies for sustainable development.

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Advances in Dye Removal Technologies

 Springer

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Preface

With increasing textile industries, the toxic and hazardous dye effluent is increasing in the ecological system due to unavailability of energy-efficient and inexpensive treatment methods. The book presents a detailed understanding of various advanced dye removal technologies. The application of the developed technologies in the context of textile effluent treatment is presented. With stringent environmental norms, the need for efficient and economic treatment option is warranted. The proposed monograph describes the rationale behind the application of the treatment technologies compared to conventional processes like microbial degradation, coagulation, ion exchange, etc. Depending on the type and concentration of dyes in the effluent, different technologies may be appropriate. The effect of various treatment conditions and operating conditions are key factors in determining the efficiency of the removal process. The mass transfer mechanism behind the separation process is also analyzed and presented in this book.

Experimental investigations have been carried out to adsorb different dyes from aqueous medium using commercial activated charcoal as an adsorbent and are described in Chap. 2. Synthetic solution of three dyes, chrysoidine, eosin, and Congo red, in aqueous medium is used for the adsorption study. Effects of adsorbent dose, initial dye concentration, contact time, pH, and temperature have been studied for the adsorption of each dye under stirred batch condition. Breakthrough curve for the column adsorption has been generated for the adsorption of eosin dye. Standard adsorption isotherms have been considered to explain the experimental equilibrium data. The rate of adsorption has been described by both first- and pseudo-second-order kinetic models. A two-resistance mass transfer model for batch adsorption process is presented that includes a film mass transfer coefficient and an internal effective diffusivity controlling the internal mass transport process based on the pore diffusion mechanism. Validation of model is checked with the literature adsorption data.

Chapter 3 describes a detailed study of the adsorption of dyes. Three systems are selected for the adsorption study. Aqueous synthetic solutions of crystal violet and methylene blue in a single-component system are selected for the primary study.

Actual textile effluent containing a mixture of two reactive dyes is used for further study. Aqueous synthetic solutions of the reactive dyes in a single-component system as well as two-component mixture of the dyes are studied. Experimental studies consist of preparation of the adsorbent, equilibrium, and kinetic studies in each system. Adsorption equilibrium data are fitted with various isotherms. A mass transfer model having a film mass transfer coefficient and an internal effective diffusivity is used for the prediction of the concentration profiles of the dyes in batch adsorption for both single-component and two-component systems.

Chapter 4 describes a systematic study of the regeneration of spent carbon (obtained after adsorption of different toxic dyes) using a novel, in situ, low-energy surfactant-enhanced carbon regeneration technique. Experimental investigations have been carried out for the regeneration of spent carbon applying surfactant-enhanced carbon regeneration technique using different types of cationic and anionic surfactants. An empirical kinetic model for the regeneration of adsorbent is presented.

The nanofiltration of the dyes is discussed in Chap. 5. An aqueous synthetic solution of crystal violet and methylene blue in a single-component system is used for the initial study. Using a suitable molecular weight cutoff (MWCO) membrane, a fractionation study is carried out with the aqueous synthetic mixture of crystal violet and methylene blue. Actual textile effluent (containing a mixture of the reactive dyes) is used for the final study. Nanofiltration is carried out in two different process configurations: an unstirred batch system and a steady-state cross flow system. Experiments are conducted in each system to observe the effects of various process parameters on the permeate concentration and flux profile. Theoretical model for unstirred batch system is developed for the single-component as well as the two-component system and tested with the data. Evaluation of the model parameters, viz., diffusivity and real retention, is carried out using profile optimization of the experimental data. Film theory is used to explain the experimental data in the cross flow system.

The application of the proposed combination processes involving (i) adsorption followed by nanofiltration and (ii) advance oxidation followed by nanofiltration is represented in Chap. 6. A detailed parametric study is carried out for both the processes (combination method). The performance of different combinations of separation technologies is discussed in detail.

In Chap. 7, micellar-enhanced ultrafiltration of dye is discussed. Aqueous synthetic solution of dye is used as feed of the micellar-enhanced ultrafiltration system. The micellar-enhanced ultrafiltration experiments are carried out in two process configurations: an unstirred batch system and a steady-state cross flow system. All the experiments are conducted to observe the effects of various process parameters on the retention of solute and permeate flux. A resistance in series model is used to quantify the flux decline in the batch system. The different resistances and growth kinetics of the gel layer have been investigated as function of the operating conditions. A two-step chemical treatment process for the recycling of surfactant from the permeate and retentate stream has been proposed, and its performance has been discussed in this chapter.

Cloud point extraction of toxic dyes is represented in Chap. 8. An aqueous synthetic solution of chrysoidine, Congo red, and eosin in a single-component system is used for the initial study. Effects of different operating parameters, e.g., concentration of the feed mixture (both dye and surfactant), pH, temperature, and the presence of mono- and divalent salt on the extraction of both the dye and surfactant, have been studied in detail. The performance of two nonionic surfactants is investigated to extract dye from the synthetic dye solution. From the experimental data, a solubilization isotherm is developed to quantify the amount of Congo red and eosin solubilization. A method has been proposed to design a cloud point extractor for the separation of Congo red and eosin dye. To test the efficiency of surfactant recovery from the dilute phase, a solvent extraction technique has been adopted and explained in detail in the same chapter.

Electrocoagulation of dyes is a powerful method of disintegration of dyes in wastewater. The electrochemical pathway leading to degradation and the effects of various operating conditions (strength of current, electrode material, electrolytes, etc.) are discussed elaborately in Chap. 9. The economics of the process is also discussed. Emulsion liquid membrane is a relatively new technology used for the extraction and separation of metal ions and bioactive materials. Chapter 10 deals with extraction of textile dyes from water using a double emulsion. The relative effect of surfactant, alkali, feed concentration, etc., on the separation efficiency is described in detail.

We hope that the book will be useful to engineers and researchers working in the field of chemical engineering, environmental studies, water technology, civil engineering, and industrial engineering. We have tried our best to make this book comprehensive and hope that it will ignite further research and development in the relevant domains of engineering. We sincerely hope that the readers will be benefitted from the book and inspired to implement them in practice. Although we have put in our best efforts to organize and present all information regarding dye removal technologies, any suggestion for improvements will be gratefully acknowledged from the readers.

The authors would like to acknowledge all dear and near ones, who have directly or indirectly inspired and influenced in preparing the contents of this book. Dr. Mondal would also like to acknowledge that this work was completed while he was at the Department of Chemical Engineering, IIT Kharagpur, during his PhD, and thank his supervisor and colleagues for their support during the same.

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Contents

1	Introduction	1
1.1	Environmental Problems Associated with the Colored Industrial Effluent	3
1.2	Toxicity Levels and Allowable Limits of Various Dye Concentrations in Streams	5
1.3	Existing Processes for the Separation of Dye from Wastewater	5
1.4	Molecular Structures of Commonly Found Dyes in Wastewater	9
	References	47
2	Adsorption of Dyes	49
2.1	Application of Adsorption in the Treatment of Process Wastewater	50
2.2	Experimental Studies of Dye Adsorption	50
2.2.1	Batch Adsorption	50
2.2.2	Column Adsorption	63
2.3	Generalized Shrinking Core Model for Batch Adsorption Data	63
2.3.1	Numerical Analysis	67
2.4	Discussion of Mathematical Model Analysis	68
2.4.1	Thomas Model (Thomas 1944)	68
2.4.2	Adams-Bohart Model (Bohart and Adams 1920)	70
2.4.3	Yoon-Nelson Model (Yoon and Nelson 1984)	71
2.4.4	Clark Model (Clark 1987)	71
2.4.5	Bed Depth/Service Time (BDST) Model (Goel et al. 2005)	71
2.4.6	Pore Diffusion-Adsorption Model	72
2.5	Various Types of Adsorbents Used for Dye Adsorption	73
	References	92

3	Adsorption of Dyes from Actual Effluent	99
3.1	Characterization of the Textile Effluent	100
3.2	Characterization of the Adsorbent	100
3.3	Adsorption Equilibrium Studies	101
3.3.1	Effect of Temperature on the Equilibrium Study of Crystal Violet and Methylene Blue	103
3.3.2	Effect of Adsorbent Particle Sizes on the Equilibrium Study of Crystal Violet and Methylene Blue	105
3.3.3	Equilibrium Isotherm Studies for Crystal Violet and Methylene Blue	105
3.3.4	Equilibrium Study with the Reactive Dyes	109
3.3.5	Single Component Systems	110
3.3.6	Two-Component System	112
3.4	Adsorption Kinetic Studies	113
3.4.1	Comparison of the Dye Removal Rate of CSD and GAC	114
3.4.2	Effect of pH on the Rate of Adsorption	115
3.4.3	Effect of Stirrer Speed in the Adsorption	116
3.4.4	Modeling of Adsorption Kinetics	116
3.4.5	Two-Component System	117
3.4.6	Model Predictions of the Kinetic Data	121
3.4.7	Effect of Particle Size	123
3.4.8	Effect of Initial Dye Concentration	126
3.4.9	Effect of Temperature	126
3.4.10	Effect of Adsorbent Loading	127
3.4.11	Kinetic Study of the Reactive Dye System	127
3.4.12	Effect of pH	127
3.4.13	Effect of Particle Size of Adsorbent	129
3.4.14	Effect of Initial Concentration of Dye	130
3.4.15	Model Predictions of the Kinetic Data for the Two-Component System	131
3.4.16	Sensitivity Analysis of the Model Parameters	131
3.5	Adsorption Studies Using Industrial Effluent	134
	References	138
4	Surfactant-Enhanced Carbon Regeneration	141
4.1	Basics of Surfactant-Enhanced Carbon Regeneration	142
4.2	Experimental Study of Desorption	142
4.2.1	Desorption Kinetic Model	143
4.3	Effect of pH	144
4.4	Effect of Different Surfactants	145
4.4.1	Desorption of Chrysoidine	145
4.4.2	Desorption of Eosin	147
4.4.3	Desorption of Congo Red	150
	References	151

5	Nanofiltration of Dyes	153
5.1	Theoretical Description of Membrane Filtration of Dyes	155
5.1.1	Single Component System	155
5.1.2	Solution Strategy	159
5.1.3	Two-Component System	160
5.1.4	Solution Strategy	164
5.1.5	Cross Flow System	166
5.2	Experiments in Unstirred Batch Cell	167
5.2.1	Single Component System	167
5.2.2	Two-Component System	173
5.3	Nanofiltration of the Textile Effluent	179
5.3.1	Estimations from Model for Two-Component System	181
5.4	Nanofiltration of the Textile Effluent in Hollow Fiber Membrane System	189
	References	196
6	Hybrid Treatment Method of Industrial Effluent	199
6.1	Adsorption Followed by Nanofiltration	202
6.1.1	Adsorption Equilibrium	202
6.1.2	Adsorption Rate	203
6.1.3	Cross Flow Flat Sheet Membrane Filtration	204
6.1.4	Direct Nanofiltration	207
6.1.5	Comparison of Adsorption Followed by Nanofiltration and Direct Nanofiltration	207
6.2	Advanced Oxidation Processes (AOP) Followed by Nanofiltration	209
6.2.1	Two-Stage Nanofiltration	214
6.2.2	Comparison of AOP Followed by Nanofiltration (Scheme 1) and Two-Stage Nanofiltration (Scheme 2)	215
6.3	Adsorption Followed by Microfiltration	217
	References	224
7	Micellar-Enhanced Ultrafiltration (MEUF)	227
7.1	Micelle Formation and Solubilization	228
7.2	Selection of Surfactant	229
7.3	Applications of MEUF	230
7.4	Micellar-Enhanced Ultrafiltration of Dye	231
7.4.1	Effects of Operating Pressure and Feed CPC Concentration on the Permeate Flux and Observed Retention of Eosin	233
7.4.2	Effects of Feed Eosin Concentration on the Observed Retention of Dye at Fixed CPC Concentration	234
7.4.3	Flux Decline Mechanism	235

7.5	Theoretical Analysis	237
7.5.1	Short-Term Flux Decline: Reversible Pore Blocking ($t < 180$ s)	238
7.5.2	Long-Term Flux Decline: Growth of Gel-Type Layer ($t > 180$ s)	239
7.5.3	Determination of the Constants in Short-Term Flux Decline	241
7.5.4	Total Resistance	241
7.5.5	Determination of the Specific Resistance of the Gel-Type Layer	242
7.5.6	Determination of the Constants in the Reversible Pore Blocking Model	242
7.5.7	Determination of the Gel Concentration of CPC Micelles	242
7.5.8	Determination of the Gel Porosity	243
7.5.9	Analysis of Various Resistances	243
7.6	MEUF in Continuous Cross Flow Cell	249
7.6.1	Effect of the Feed CPC Concentration on Permeate Flux and the Retention of Both Dye and CPC	249
7.6.2	Effect of the Feed Dye Concentration on the Permeate Flux and Retention of Both Dye and CPC	250
7.6.3	Effect of Pressure Drop on the Observed Retention of Dye and Permeate Flux	251
7.6.4	Effect of Cross Flow Rate on the Observed Retention of Dye and Permeate Flux	251
7.7	Regeneration of Surfactant from the Permeate and Retentate Stream	252
7.7.1	Procedure	252
7.7.2	Regeneration of Surfactant from Permeate Stream	253
7.7.3	Regeneration of Surfactant from Retentate Stream	254
	References	254
8	Cloud Point Extraction	257
8.1	Mechanism of Phase Separation	258
8.2	Applications of Cloud Point Separation	259
8.3	Effects of Surfactant Concentration on Extraction	259
8.3.1	Chrysoidine	260
8.3.2	Eosin	261
8.3.3	Congo Red	263
8.4	Effects of Dye Concentration on Extraction	265
8.4.1	Chrysoidine	265
8.4.2	Eosin and Congo Red	266

8.5	Effects of Temperature on Extraction	267
8.5.1	Chrysoidine	267
8.5.2	Eosin and Congo Red	269
8.6	Effects of pH on Extraction	272
8.7	Effects of Salt Concentration on Extraction	273
8.7.1	Chrysoidine	273
8.7.2	Eosin	274
8.7.3	Congo Red	275
8.8	Determination of Design Parameters for Cloud Point Extraction of Congo Red and Eosin Dyes Using TX-100	276
8.8.1	Solubilization Isotherm	277
8.8.2	Variation of Fractional Coacervate Phase Volume	280
8.8.3	Determination of Surfactant Requirement for the Removal of Dye to a Desired Level Without Using Salts	284
8.8.4	Surfactant Recovery by Solvent Extraction (SE)	285
	References	287
9	Electrocoagulation	289
9.1	Design of Electrocoagulation Unit	298
9.2	Removal of Dyes Using Electrocoagulation	300
9.2.1	Effect of Current Density	301
9.2.2	Effect of Initial Dye Concentration	302
9.2.3	Effect of Initial pH	303
9.2.4	Effect of Interelectrode Distance	303
9.2.5	Effect of Conductivity	304
9.2.6	Energy Consumption	305
9.2.7	Characterization of Treated Dye Solution and By-Products Obtained from EC Bath	306
9.2.8	Operation Cost	307
9.3	Benefits and Drawbacks of Electrocoagulation	309
	References	311
10	Emulsion Liquid Membrane	313
10.1	Emulsion Preparation	314
10.2	Effect of Surfactant Concentration	315
10.3	Effect of NaOH Concentration	317
10.4	Effect of Stirring Speed	318
10.5	Effect of Feed Concentration	320
	References	322

List of Figures

Fig. 1.1	Major textile exporters in the world in 2012	2
Fig. 1.2	Typical amount of water consumed (in m ³ /1000 liters of product) in a conventional continuous process	3
Fig. 1.3	The typical amounts of fixed and unfixed dye concentration used for dyeing fibers (EWA 2005)	4
Fig. 2.1a	Effects of agitation time and concentration of chrysoidine on percentage of adsorption	51
Fig. 2.1b	Effects of agitation time and concentration of eosin on percentage of adsorption	51
Fig. 2.1c	Effects of agitation time and concentration of Congo red on percentage of adsorption	52
Fig. 2.2	Effects of agitation time and adsorbent dose on percentage adsorption	53
Fig. 2.3a	Effect of initial pH on percentage of adsorption for 400 mg/L of feed chrysoidine	53
Fig. 2.3b	Effect of pH on the percentage adsorption of feed eosin	54
Fig. 2.3c	Effect of initial pH on percentage of adsorption for 200 mg/L of feed Congo red	54
Fig. 2.4a	Effect of temperature on adsorption capacity for 400 mg/L of feed chrysoidine	56
Fig. 2.4b	Effect of temperature on adsorption capacity for 100 mg/L of feed eosin	56
Fig. 2.4c	Effect of temperature on adsorption capacity for 100 mg/L of feed Congo red	57
Fig. 2.5a	Adsorption isotherms of chrysoidine on activated carbon	59
Fig. 2.5b	Adsorption isotherms of eosin on activated carbon	60
Fig. 2.5c	Adsorption isotherms of Congo red on activated carbon	60

Fig. 2.6a	Plot of the pseudo-second-order kinetic model for adsorption of chrysoidine on activated carbon (0.5 g/L). Feed chrysoidine: 200 and 400 mg/L	61
Fig. 2.6b	Plot of the pseudo-second-order kinetic model for adsorption of eosin on activated carbon (1.0 g/L). Feed eosin: 200 and 400 mg/L	62
Fig. 2.6c	Plot of the pseudo-second-order kinetic model for adsorption of Congo red on activated carbon (1.0 g/L). Feed Congo red: 50 and 545 mg/L	62
Fig. 2.7	Variation of the breakthrough curve with bed depth	64
Fig. 2.8a	Adsorption of Astrazone blue dye on silica	69
Fig. 2.8b	Effect of initial adsorbate concentration. <i>Solid lines</i> are the model predictions and <i>symbols</i> are the experimental data	69
Fig. 2.8c	Effect of the mass of adsorbent on concentration decay. <i>Solid lines</i> are the model predictions and <i>symbols</i> are the experimental data	69
Fig. 2.8d	Effect of silica particle size on concentration decay. <i>Solid lines</i> are the model predictions and <i>symbols</i> are the experimental data	70
Fig. 3.1	Image of charred saw dust in scanning electron microscope	101
Fig. 3.2	Image of granular activated carbon in scanning electron microscope	101
Fig. 3.3	Equilibrium adsorption of CV and MB on CSD and comparison with GAC ($T = 298 \text{ K}$; $d_p = 0.044 \text{ mm}$)	102
Fig. 3.4	Equilibrium adsorption of crystal violet on CSD at different temperatures	103
Fig. 3.5	Equilibrium adsorption of methylene blue on CSD at different temperatures	104
Fig. 3.6	Equilibrium adsorption of crystal violet on CSD at different particle sizes	106
Fig. 3.7	Equilibrium adsorption of methylene blue on CSD at different particle sizes	106
Fig. 3.8	Linearized Langmuir plot at different operating conditions for crystal violet	108
Fig. 3.9	Linearized Langmuir plot at different operating conditions for methylene blue	109
Fig. 3.10	Equilibrium adsorption of the reactive dyes in single component systems and in mixture	111
Fig. 3.11	Comparison between the experimental and estimated Y_e values for reactive black	112
Fig. 3.12	Comparison between the experimental and estimated Y_e values for reactive red	113
Fig. 3.13	Concentration decay of CV using CSD and comparison with GAC ($C_o = 150 \text{ mg/l}$, $d_p = 0.044 \text{ mm}$, $T = 298 \text{ K}$, $M_a = 0.5 \text{ g}$)	114

Fig. 3.14	Concentration decay of MB using CSD and comparison with GAC ($C_o = 150$ mg/l, $d_p = 0.044$ mm, $T = 298$ K, $M_a = 0.5$ g)	115
Fig. 3.15	Effect of pH on the adsorption of the crystal violet and methylene blue ($C_o = 150$ mg/l, $d_p = 0.044$ mm, $T = 298$ K, $M_a = 0.5$ g)	116
Fig. 3.16	Effect of stirrer speed on the adsorption of crystal violet ($C_o = 150$ mg/l, $d_p = 0.044$ mm, $T = 298$ K, $M_a = 0.5$ g)	117
Fig. 3.17	Effect of stirrer speed on the adsorption of MB ($C_o = 150$ mg/l, $d_p = 0.044$ mm, $T = 298$ K, $M_a = 0.5$ g)	118
Fig. 3.18	Effect of particle sizes on the concentration decay of CV ($C_o = 150$ mg/l, $T = 298$ K, $M_a = 0.5$ g)	122
Fig. 3.19	Effect of particle sizes on the concentration decay of MB ($C_o = 150$ mg/l, $T = 298$ K, $M_a = 0.5$ g)	123
Fig. 3.20	Effect of initial concentrations on the concentration decay of CV ($d_p = 0.044$ mm, $T = 298$ K, $M_a = 0.5$ g)	123
Fig. 3.21	Effect of initial concentrations on the concentration decay of MB ($d_p = 0.044$ mm, $T = 298$ K, $M_a = 0.5$ g)	124
Fig. 3.22	Effect of temperature on the concentration decay of CV ($C_o = 150$ mg/l, $d_p = 0.044$ mm, $M_a = 0.5$ g)	124
Fig. 3.23	Effect of temperature on the concentration decay of MB ($C_o = 150$ mg/l, $d_p = 0.044$ mm, $M_a = 0.5$ g)	124
Fig. 3.24	Effect of adsorbent loading on the concentration decay of CV ($C_o = 150$ mg/l, $d_p = 0.044$ mm, $T = 298$ K)	125
Fig. 3.25	Effect of adsorbent loading on the concentration decay of MB ($C_o = 150$ mg/l, $d_p = 0.044$ mm, $T = 298$ K)	125
Fig. 3.26	Effect of pH on the concentration decay of reactive red ($C_o = 150$ mg/l; $d_p = 0.044$ mm; $T = 298$ K)	128
Fig. 3.27	Effect of pH on the concentration decay of reactive black ($C_o = 150$ mg/l; $d_p = 0.044$ mm; $T = 298$ K)	128
Fig. 3.28	Effect of particle size of the adsorbent on the concentration decay of reactive red ($C_o = 150$ mg/l; pH = 2.0; $T = 298$ K)	129
Fig. 3.29	Effect of particle size of the adsorbent on the concentration decay of reactive black ($C_o = 150$ mg/l; pH = 2.0; $T = 298$ K)	129
Fig. 3.30	Effect of initial dye concentration on the concentration decay of reactive red (pH = 2.0; $d_p = 0.044$ mm; $T = 298$ K)	130
Fig. 3.31	Effect of initial dye concentration on the concentration decay of reactive black (pH = 2.0; $d_p = 0.044$ mm; $T = 298$ K)	130
Fig. 3.32	Experimental and the model fitted concentration profiles in a synthetic mixture of reactive black and reactive red ($C_{o,1}:C_{o,2} = 70.5:70$ mg/l; $M_a = 1.0$ g)	131

Fig. 3.33 Experimental and the model fitted concentration profiles in a synthetic mixture of reactive black and reactive red ($C_{o,1}:C_{o,2} = 54: 92$ mg/l; $M_a = 1.0$ g) 132

Fig. 3.34 Experimental and the model fitted concentration profiles in a synthetic mixture of reactive black and reactive red ($C_{o,1}:C_{o,2} = 101: 47$ mg/l; $M_a = 1.0$ g) 132

Fig. 3.35 Prediction of concentration profiles of reactive black and reactive red in a synthetic mixture ($C_{o,1}:C_{o,2} = 100: 100$ mg/l; $M_a = 1.0$ g) 132

Fig. 3.36 Prediction of concentration profiles of reactive black and reactive red in a synthetic mixture ($C_{o,1}:C_{o,2} = 75: 100$ mg/l; $M_a = 1.0$ g) 133

Fig. 3.37 Prediction of concentration profiles of reactive black and reactive red in a synthetic mixture ($C_{o,1}: C_{o,2} = 150: 100$ mg/l; $M_a = 1.0$ g) 133

Fig. 3.38 Effect of variations in D_{p1} on the prediction of concentration profile of reactive black ($C_{o,1}: C_{o,2} = 100: 100$ mg/l; $M_a = 1.0$ g) 134

Fig. 3.39 Effect of variations in D_{p2} on the prediction of concentration profile of reactive red ($C_{o,1}: C_{o,2} = 100: 100$ mg/l; $M_a = 1.0$ g) 134

Fig. 3.40 Concentration decay of reactive black in the industrial effluent using varying amount of the adsorbent (pH = 2.0; $d_p = 0.044$ mm; $T = 298$ K) 135

Fig. 3.41 Concentration decay of reactive red in the industrial effluent using varying amount of the adsorbent (pH = 2.0; $d_p = 0.044$ mm; $T = 298$ K) 135

Fig. 3.42 COD removal (%) with variation in the adsorbent amount (pH = 2.0; $d_p = 0.044$ mm; $T = 298$ K) 136

Fig. 3.43 Removal of Congo red (CR) and methylene blue (MB) using flyash and activated carbon. The feed concentration is 0.2 mg/l and solution pH is 7.5 136

Fig. 3.44 Removal of acid yellow 36 (C.I. 13,065) using rice husk carbon and saw dust carbon 137

Fig. 3.45 Removal of Remazol Red and Remazol Black B mixture (total concentration of 400 mg/l) using agricultural residues 138

Fig. 4.1 Schematic of the different stages of the SECR process 143

Fig. 4.2 Effect of pH on desorption of chrysoidine from spent charcoal. *Solid lines* are model fitted results and symbols are experimental data 145

Fig. 4.3 Effect of pH on desorption of eosin from spent charcoal. *Solid lines* are model fitted results and the symbols are the experimental data 145

Fig. 4.4 Effect of SDS on desorption of chrysoidine from spent charcoal. *Solid lines* are model fitted results and symbols are the experimental data 146

Fig. 4.5 Effect of TTAB on desorption of chrysoidine from spent charcoal. *Solid lines* are model fitted results and symbols are the experimental data 146

Fig. 4.6 Effect of CPC on desorption of chrysoidine from spent charcoal. *Solid lines* are model fitted results and symbols are the experimental data 147

Fig. 4.7 Effect of CPC on desorption of eosin from spent charcoal. *Solid lines* are model fitted results and symbols are the experimental data 148

Fig. 4.8 Effect of SDS on desorption of eosin from spent charcoal. *Solid lines* are model fitted results and symbols are the experimental data 148

Fig. 4.9 Effect of AOT on desorption of eosin from spent charcoal. *Solid lines* are model fitted results and symbols are the experimental data 149

Fig. 4.10 Comparison of the performance of various surfactants for the desorption of eosin. Concentration of each surfactant is 2000 mg/L 149

Fig. 4.11 Comparison of the performance of various surfactants for the desorption of Congo red. Concentration of each surfactant is 2500 mg/L (with surface loading 376 mg dye/g CAC) 150

Fig. 5.1 Variation of permeate flux of crystal violet with time at different feed concentrations and operating pressure differences in the batch cell (the solid lines are guides for the reader's eyes) 168

Fig. 5.2 Variation of observed retention of crystal violet with time at a fixed feed concentration (17.6 mg/l) in the batch cell (the solid lines are guides for the reader's eyes) 169

Fig. 5.3 Variation of observed retention of methylene blue with time at a fixed operating pressure of 415 kPa in the batch cell (the solid lines are guides for the reader's eyes) 169

Fig. 5.4 Comparison between the experimental and estimated permeate concentration profiles in the batch cell at a fixed pressure 170

Fig. 5.5 Comparison between the experimental and estimated permeate concentration profiles in the batch cell at a fixed feed concentration 171

Fig. 5.6 Variation of membrane surface concentration profiles in the batch cell at a fixed pressure 171

Fig. 5.7 Development of nondimensional concentration boundary layer with time at a fixed pressure in the batch cell 172

Fig. 5.8	Comparison between the experimental and estimated permeate flux profiles in the batch cell at a fixed pressure	172
Fig. 5.9	Comparison between the experimental and estimated permeate flux profiles in the batch cell at different operating pressures	173
Fig. 5.10	Variation of observed retention of crystal violet and methylene blue with time from a mixture of 10 mg/l each in the batch cell (solid lines are guides for the reader's eyes)	174
Fig. 5.11	Comparison between the experimental values of permeate flux at a pressure of 415 kPa in the batch cell (solid lines are guides for the reader's eyes)	174
Fig. 5.12	Variation of observed retention of crystal violet with pressure difference at different bulk velocity in the cross flow cell (solid lines are guides for the reader's eyes)	175
Fig. 5.13	Variation of permeate flux with pressure at different feed concentrations and bulk velocities (solid lines are guides for the reader's eyes)	175
Fig. 5.14	Prediction of the steady-state permeate flux in CF NF from film theory using D and R_r obtained from the batch cell results	176
Fig. 5.15	Prediction of the steady-state permeate concentration in CF NF from film theory using D and R_r obtained from the batch cell results	176
Fig. 5.16	Prediction of the steady-state permeate flux in CF NF from film theory using D and R_r obtained from the optimization of CF experimental data	177
Fig. 5.17	Prediction of the steady-state permeate concentration in CF NF from film theory using D and R_r obtained from the optimization of CF experimental data	178
Fig. 5.18	Variation of selectivity of MB with bulk velocity in a mixture of CV and MB (16 mg/l each) in the cross flow cell (solid lines are guides for the reader's eyes)	178
Fig. 5.19	Variation of permeate flux with pressure and cross flow velocity in the cross flow cell in a 50:50 mixture of CV and MB	179
Fig. 5.20	Variation of observed retention of dye 1 in a mixture of dyes with time in the batch cell for different conditions of ΔP and C_0 (solid lines are guides for the reader's eyes)	180
Fig. 5.21	Variation of observed retention of dye 2 in a mixture of dyes with time in the batch cell for different conditions of ΔP and C_0 (solid lines are guides for the reader's eyes)	180
Fig. 5.22	Variation of percentage COD removal of effluent mixture with time in the batch cell for different conditions of ΔP and C_0 (solid lines are guides for the reader's eyes)	181

Fig. 5.23	Variation of permeate flux of effluent mixture with time in the batch cell for different conditions of ΔP and C_0 (solid lines are guides for the reader's eyes)	182
Fig. 5.24	Comparison between experimental and estimated value of concentration of dye 1 and 2, respectively, at a fixed pressure of 276 kPa for two different initial concentration in batch cell	182
Fig. 5.25	Comparison between experimental and predicted values of permeate concentration of dye 1 and 2, respectively, at a fixed pressure of 550 kPa for two different initial concentrations in batch cell	183
Fig. 5.26	Effect of ratio of initial feed concentration on permeate concentration for constant pressure difference	183
Fig. 5.27	Effect of operating pressure difference on permeate concentration for constant initial feed concentration (model estimated)	184
Fig. 5.28	Effect of operating pressure difference on membrane surface concentration for constant initial feed concentration ratio (model estimated)	185
Fig. 5.29	Effect of ratio of initial feed concentration on membrane surface concentration for constant pressure difference (model estimated)	185
Fig. 5.30	Comparison between experimental and estimated values of permeate flux at a fixed concentration ($C_{01}:C_{02} = 25:15$) but different pressures in batch cell	186
Fig. 5.31	Comparison between experimental and estimated values of permeate flux at a fixed concentration ($C_{01}:C_{02} = 13:7$) but different pressures in batch cell	186
Fig. 5.32	Effect of operating pressure difference on permeate flux for constant initial feed concentration ratio (model estimated)	187
Fig. 5.33	Effect of ratio of initial feed concentration on permeate flux for constant pressure difference (model estimated)	187
Fig. 5.34	Variation of retention of the two dyes in the effluent mixture with pressure at same feed concentration (25:15) but different cross flow velocities	187
Fig. 5.35	Variation of retention of the two dyes in the effluent mixture with pressure at same feed concentration (13:7) but different cross flow velocities	188
Fig. 5.36	Variation of COD removal with cross flow velocity and transmembrane pressure drop during cross flow NF	189
Fig. 5.37	Variation of permeate flux of the industrial effluent with transmembrane pressure drop at two different feed concentrations	189
Fig. 5.38	Permeate flux profiles for different hollow fiber NF membranes	192

Fig. 5.39	FRR and FDR of textile effluent for different NF membranes	194
Fig. 5.40	Flux decline profile for NF of textile effluent using 440 Da MWCO hollow fiber membrane	194
Fig. 6.1	Comparison of removal of crystal violet using two schemes: (i) direct NF and (ii) adsorption followed by NF	201
Fig. 6.2	Equilibrium adsorption of the reactive dyes in single component system (<i>solid lines</i> are guides for author's eyes)	203
Fig. 6.3	Comparison between the experimental and calculated Y_e values of the dyes in mixture	204
Fig. 6.4	Effect of adsorbent loading on the concentration decay of dye 1 (<i>solid lines</i> are guides for author's eyes)	204
Fig. 6.5	Effect of adsorbent loading on the concentration decay of dye 2 (<i>solid lines</i> are guides for author's eyes)	205
Fig. 6.6	Variation of permeate concentration of dye 1 with pressure and cross flow velocity (<i>solid lines</i> are guides for author's eyes)	205
Fig. 6.7	Variation of permeate concentration of dye 2 with pressure and cross flow velocity (<i>solid lines</i> are guides for author's eyes)	206
Fig. 6.8	Variation of permeate flux with pressure and cross flow velocity (<i>solid lines</i> are guides for author's eyes)	206
Fig. 6.9	Comparison of the three methods for the removal of dye 1 from industrial effluent	209
Fig. 6.10	Comparison of the three methods for the removal of dye 2 from industrial effluent	209
Fig. 6.11	Variation of percentage flux increment with pressure and cross flow velocity in the combination method (cross flow velocities are, 1–14 cm/s, 2–21 cm/s and 3–28 cm/s)	210
Fig. 6.12	Effect of $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$ on degradation of CR and CB in AOP	211
Fig. 6.13	Effect of H_2O_2 on degradation of CR and CB in AOP	212
Fig. 6.14	Variation of CR and CB concentrations with operating pressure in permeate in NF	213
Fig. 6.15	Variation of permeate flux with operating pressure in NF	213
Fig. 6.16	Variation of permeate flux with operating pressure in step 1 (NF)	215
Fig. 6.17	Variation of CR and CB concentrations with operating pressure in permeate after first stage NF	215
Fig. 6.18	Variation of permeate flux with operating pressure after two-stage NF	216
Fig. 6.19	Variation of CR and CB concentrations with operating pressure in permeate after two-stage NF	216

Fig. 6.20 Effect of (a) pH and (b) salt concentration on adsorption of reactive dyes on activated carbon 219

Fig. 6.21 Profiles of permeate flux under cross flow recycle mode (dye concentration, 50 mg/l). (a) Reactive yellow dye, (b) reactive black dye (c) reactive red dye, (d) reactive brown dye 220

Fig. 6.22 Profiles of permeate flux under cross flow under cross flow recycle mode (dye concentration, 150 mg/l). (a) Reactive yellow dye, (b) reactive black dye, (c) reactive red dye, (d) reactive brown dye 222

Fig. 6.23 Percentage adsorption of (a) 50 mg/l and (b) 150 mg/l of reactive dyes with adsorbent dose 223

Fig. 6.24 Profiles of (a) permeate flux and (b) VCF under batch mode of cross flow filtration 223

Fig. 7.1 Variation of observed retention of eosin with time at different operating pressure differences. Feed eosin concentration is $10 \times 10^{-3} \text{ kg/m}^3$ and CPC concentration is 10 kg/m^3 231

Fig. 7.2 Variation of the permeate flux with time at different operating pressure differences. Feed eosin concentration is $10 \times 10^{-3} \text{ kg/m}^3$ and CPC concentration is 10 kg/m^3 232

Fig. 7.3 Variation of permeate flux with CPC to eosin ratio at different pressures at the end of experiment. Feed eosin concentration is $10.0 \times 10^{-3} \text{ kg/m}^3$ 233

Fig. 7.4 Variation of eosin retention with CPC to eosin ratio at different pressures after 1 h of experiment. Feed concentrations are eosin $10 \times 10^{-3} \text{ kg/m}^3$ and CPC 5, 10, 20, and 25 kg/m^3 234

Fig. 7.5 Variation of eosin retention with CPC to eosin ratio at 276 kPa 235

Fig. 7.6 Variation of CPC retention with CPC to eosin ratio 236

Fig. 7.7 Variation of l/v_w^2 with time at different pressure. Feed eosin concentration is $10 \times 10^{-3} \text{ kg/m}^3$ and CPC concentration is 10 kg/m^3 236

Fig. 7.8 Variation of l/v_w^2 with time at different pressure. Feed eosin concentration is $10 \times 10^{-3} \text{ kg/m}^3$ and CPC concentration is 20 kg/m^3 237

Fig. 7.9 Variation of short-term flux decline with time at different pressure. Feed eosin concentration is $10 \times 10^{-3} \text{ kg/m}^3$ and CPC concentration is 25 kg/m^3 238

Fig. 7.10 Variation of steady-state permeate flux with feed CPC concentration (eosin concentration is constant at $10 \times 10^{-3} \text{ kg/m}^3$ for all the cases) at 276 kPa pressure and 500 rpm 243

Fig. 7.11 Variation of the permeate flux with time at different operating pressure differences. Feed eosin concentration is $10 \times 10^{-3} \text{ kg/m}^3$ and CPC concentration is 10 kg/m^3 244

Fig. 7.12	Variation of the permeate flux with time at different operating pressure differences. Feed eosin concentration is $10 \times 10^{-3} \text{ kg/m}^3$ and CPC concentration is 20 kg/m^3	244
Fig. 7.13	Variation of dimensionless pore blocking resistance with time at different operating pressures	246
Fig. 7.14	Variation of dimensionless pore blocking resistance with CPC to eosin ratio at different pressures after 180 s of experiment. Feed eosin concentration is $10 \times 10^{-3} \text{ kg/m}^3$	246
Fig. 7.15	Variation of dimensionless gel-type layer resistance with time at different operating pressure	247
Fig. 7.16	Variation of dimensionless gel-type layer resistance with CPC to eosin ratio at different pressures after 1 h of experiment. Feed eosin concentration is $10 \times 10^{-3} \text{ kg/m}^3$	247
Fig. 7.17	Variation of dimensionless total resistance with time at different operating pressure	248
Fig. 7.18	Variation of dimensionless total resistance with CPC to eosin ratio at different pressures after 1 h of experiment. Feed eosin concentration is $10 \times 10^{-3} \text{ kg/m}^3$	248
Fig. 7.19	Variation of the thickness of the gel layer with time at different operating pressure	248
Fig. 7.20	Variation of the thickness of the gel layer with time at different feed CPC concentration	249
Fig. 7.21	Effect of the feed CPC concentration on permeate flux and the retention of both dye and CPC	250
Fig. 7.22	Effect of the feed dye concentration on the permeate flux and retention of both dye and CPC	250
Fig. 7.23	Effect of pressure on the observed retention and the permeate flux	251
Fig. 7.24	Effect of cross flow rate on the observed retention and the permeate flux	252
Fig. 7.25	Schematic of the chemical reactions involved during regeneration	253
Fig. 8.1	Effect of surfactant concentration on extraction of dye	260
Fig. 8.2	Effect of surfactant concentration on the partition coefficient of surfactant	262
Fig. 8.3	Effect of concentrations of TX-100 and eosin on the efficiency of CPE of dye at 80°C	262
Fig. 8.4	Effect of concentrations of TX-100 and eosin on the efficiency of CPE of dye at 95°C	263
Fig. 8.5	Effect of concentrations of TX-100 and Congo red on the CPE of dye at 70°C	264
Fig. 8.6	Effect of concentrations of TX-100 and Congo red on the CPE of dye at 85°C	264

Fig. 8.7	Effect of feed dye concentration on the dilute-phase dye concentration	265
Fig. 8.8	Effect of concentration of TX-100 on the CPE of TX-100 at different feed eosin concentrations at 85 °C	266
Fig. 8.9	Effect of concentration of TX-100 on the CPE of TX-100 at different feed Congo red concentrations at 70 °C	267
Fig. 8.10	Effect of temperature on the dye extraction at different TX-100 concentrations and at a dye concentration of 100 ppm	268
Fig. 8.11	Effect of temperature on the dye extraction at different dye concentrations and at a TX-114 concentration of 0.075(M) . . .	268
Fig. 8.12	Effect of temperature on the efficiency of CPE for 10 ppm of feed dye	269
Fig. 8.13	Effect of temperature on the efficiency of CPE for 150 ppm of feed dye	270
Fig. 8.14	Effect of temperature on the efficiency of CPE for 139, 275, and 555 ppm of CR at TX-100 concentrations of 0.04 and 0.05(M)	270
Fig. 8.15	Effect of temperature on the fractional coacervate phase volume at different feed eosin concentrations and at TX-100 concentration of 0.05(M)	271
Fig. 8.16	Effect of temperature on the fractional coacervate phase volume at different feed CR concentrations and at TX-100 concentration of 0.1(M)	271
Fig. 8.17	Effect of temperature on CPE of TX-100 at different feed dye and TX-100 concentrations	272
Fig. 8.18	Effect of pH on extraction of dye using TX-100 and TX-114 . . .	273
Fig. 8.19	Effect of NaCl and CaCl ₂ concentration on extraction of chrysoidine	274
Fig. 8.20	Effect of NaCl concentration on fractional coacervate phase volume	274
Fig. 8.21	Effect of NaCl concentration on the CPE for 200 ppm of feed eosin	275
Fig. 8.22	Effect of CaCl ₂ concentration on the efficiency of CPE for 400 ppm of feed CR at 0.03(M) of TX-100	276
Fig. 8.23	Effect of CaCl ₂ concentration on the efficiency of CPE for 600 ppm of feed CR at 0.03(M) of TX-100	276
Fig. 8.24	Solubilization isotherm for Congo red at different temperatures using TX-100	277
Fig. 8.25	Solubilization isotherm for eosin at different temperatures using TX-100	278
Fig. 8.26	Variation of the values of <i>m</i> and <i>n</i> with temperature for solubilization of Congo red in TX-100	278
Fig. 8.27	Variation of the values of <i>m</i> and <i>n</i> with temperature for solubilization of eosin in TX-100	279

Fig. 8.28	Isotherm for the solubilization of 600 mg/L of Congo red in 0.03 (M) of TX-100 micelles at 70 °C in presence of CaCl ₂	280
Fig. 8.29	Isotherm for the solubilization of 200 mg/L of eosin in 0.1(M) of TX-100 micelles at 85 °C in presence of NaCl	280
Fig. 8.30	Variation of the values of <i>a</i> and <i>b</i> with temperature for solubilization of Congo red in TX-100	281
Fig. 8.31	Variation of the values of <i>a</i> and <i>b</i> with temperature for solubilization of eosin in TX-100	281
Fig. 8.32	Variation of the values of <i>P</i> and <i>R</i> with temperature for solubilization of Congo red in TX-100	282
Fig. 8.33	Variation of the values of <i>P</i> and <i>R</i> with temperature for solubilization of eosin in TX-100	282
Fig. 8.34	Variation of fractional coacervate phase volume with initial TX-100 concentration at different temperatures for Congo red	283
Fig. 8.35	Variation of fractional coacervate phase volume with initial TX-100 concentration at different temperatures for eosin	283
Fig. 8.36	Variation of the requirement of TX-100 concentration for different initial Congo red concentrations at three different temperatures to bring down its dilute-phase concentration to 1 ppm (1.435×10^{-3} mM)	285
Fig. 8.37	Variation of the requirement of TX-100 concentration for different initial eosin concentrations at three different temperatures to bring down its dilute-phase concentration to 1 ppm (1.445×10^{-3} mM)	286
Fig. 8.38	Effect of heptane to aqueous phase volumetric ratio on the extraction of TX-100 at different feed TX-100 concentrations	287
Fig. 9.1	Interactions within the electrocoagulation process	290
Fig. 9.2	Distribution diagram for Al-H ₂ O considering only mononuclear species	293
Fig. 9.3	The solubility diagram for aluminum hydroxide, Al(OH) ₃ (s) ...	294
Fig. 9.4	Potential pH diagram for the system aluminum-water at 25 °C	295
Fig. 9.5	Pathway of general electrode reaction	298
Fig. 9.6	Variation of concentration of crystal violet dye with time at different current densities. Interelectrode distance, 0.005 m; initial dye concentration, 100 mg/L; pH, 8.5; conductivity, 1.613 S/m	302
Fig. 9.7	Variation of extent of dye removal with time for different initial dye concentrations. Interelectrode distance, 0.005 m; current density, 11.125 A/m ² ; pH, 8.5; conductivity, 1.613 S/m	302
Fig. 9.8	Effects of solution pH on the dye removal. Interelectrode distance, 0.005 m; current density, 11.125 A/m ² ; conductivity, 1.613 S/m; initial dye concentration, 100 mg/L; time, 60 min . . .	303

Fig. 9.9	Effects of interelectrode distance on the dye removal. Current density, 11.125 A/m^2 ; conductivity, 1.613 S/m ; initial dye concentration, 100 mg/L ; time, 60 min ; pH, 8.5	304
Fig. 9.10	Effects of solution conductivity over dye removal and cell voltage. Current density, 11.125 A/m^2 ; conductivity, 1.613 S/m ; initial dye concentration, 100 mg/L ; time, 60 min ; pH, 8.5 ; interelectrode distance, 0.005 m	305
Fig. 9.11	Effect of current density on percentage removal of dye and energy consumption. Initial dye concentration, 100 mg/L ; conductivity, $16.13 \times 10^{-1} \text{ S/m}$; pH, 8.5 ; interelectrode distance, $0.5 \times 10^{-2} \text{ m}$	307
Fig. 9.12	Absorption spectra of EC-treated samples with time (taken after every 10 min)	307
Fig. 9.13	SEM image of by-products obtained from EC bath	308
Fig. 9.14	Elemental analysis of the by-products obtained from EC bath	308
Fig. 9.15	Cost for the treatment of dye solution containing different concentration of crystal violet. Current density, 11.125 A/m^2 ; conductivity, 1.613 S/m ; pH, 8.5 ; interelectrode distance, 0.005 m	310
Fig. 10.1	Liquid emulsion membrane droplet	314
Fig. 10.2	Variation of extraction of CV with time for different span 80 concentrations	315
Fig. 10.3	Variation of % extraction of MB with time for different span 80 concentrations	316
Fig. 10.4	Effect of span 80 concentration in binary mixture	317
Fig. 10.5	Variation of extraction of CV with time for different NaOH concentrations	318
Fig. 10.6	Variation of % extraction of MB with time for different NaOH concentrations	318
Fig. 10.7	Effect of NaOH concentration in binary mixture	319
Fig. 10.8	Variation of extraction of CV with time for different stirring speeds	319
Fig. 10.9	Variation of extraction of MB with time for different stirring speeds	320
Fig. 10.10	Effect of stirring speed volume in binary mixture	320
Fig. 10.11	Variation of CV concentration with time for different feed CV concentrations	321
Fig. 10.12	Variation of MB concentration with time for different feed MB concentrations	321
Fig. 10.13	Effect of dye concentration in binary mixture	322

List of Tables

Table 1.1	Categories of dye based on dyeing process and applications ...	2
Table 1.2	Environmental discharge limits of the various developing nations across the globe	6
Table 1.3	Brief summary on different types of dye removal treatment processes	9
Table 1.4	Molecular structure of various commercially available dyes ...	11
Table 2.1	Low-cost high-capacity metal ion adsorbents	50
Table 2.2a	Thermodynamic parameters for adsorption of chrysoidine in activated charcoal at different temperature and dye concentrations	58
Table 2.2b	Thermodynamic parameters for adsorption of eosin in activated charcoal at different temperature and 100 mg/L of eosin	58
Table 2.2c	Thermodynamic parameters for adsorption of Congo red in activated charcoal at different temperature and dye concentrations	58
Table 2.3	Langmuir and Freundlich isotherm constants for adsorption of dyes on activated charcoal	60
Table 2.4a	Comparison of the first- and second-order adsorption rate constants, calculated and experimental q_e value for chrysoidine on activated charcoal	62
Table 2.4b	Comparison of the first- and second-order adsorption rate constants, calculated and experimental q_e value for eosin on activated charcoal	63
Table 2.4c	Comparison of the first- and second-order adsorption rate constants, calculated and experimental q_e value for Congo red on activated charcoal	63
Table 2.5	Radke-Prausnitz isotherm constants $\left[\left(\frac{1}{Y_e}\right) = \left(\frac{1}{AC_c}\right) + \left(\frac{1}{BC_e^{\delta}}\right)\right]$	68
Table 2.6	Model parameters using Radke-Prausnitz isotherm at various temperatures	68

Table 2.7	Adsorption capacities of commercial activated carbon and other alternative adsorbents for removal of acid dyes	74
Table 2.8	Adsorption capacities of commercial activated carbon and other alternative adsorbents for removal of basic dyes	78
Table 2.9	Adsorption capacities of commercial activated carbon and other alternative adsorbents for removal of dyes (apart from acid or basic dyes)	86
Table 3.1	Characterization of the effluent from the textile plant	100
Table 3.2	Physical properties of the adsorbents	101
Table 3.3	Thermodynamic parameters for the adsorption of crystal violet by CSD	105
Table 3.4	Thermodynamic parameters for the adsorption of methylene blue by CSD	105
Table 3.5	Langmuir constants for CV – CSD systems	106
Table 3.6	Langmuir constants for MB – CSD systems	107
Table 3.7	Freundlich Constants for CV – CSD systems	107
Table 3.8	Freundlich Constants for MB – CSD systems	107
Table 3.9	Redlich-Peterson constants for CV – CSD system	107
Table 3.10	Redlich-Peterson constants for MB – CSD system	107
Table 3.11	Fritz-Schlunder constants for CV – CSD system	108
Table 3.12	Fritz-Schlunder constants for MB – CSD system	108
Table 3.13	Radke-Prausnitz constants for CV – CSD system	110
Table 3.14	Radke-Prausnitz constants for MB – CSD system	110
Table 3.15	Temkin constants for CV – CSD systems	110
Table 3.16	Temkin constants for MB – CSD systems	110
Table 3.17	Langmuir constants for reactive dye systems	111
Table 3.18	Freundlich constants for reactive dye systems	111
Table 3.19	Redlich-Peterson constants for reactive dye systems	111
Table 3.20	Fritz-Schlunder constants for reactive dye systems	111
Table 5.1	Pressure-driven membrane processes	154
Table 5.2	Model parameter values for the two-component system	167
Table 5.3	Properties measured for the textile effluent during NF in the cross flow cell	190
Table 5.4	Effluent characteristics of textile plant	191
Table 5.5	Permeate characteristics of the treated effluent at 20 l/h cross flow rate and 104 kPa transmembrane pressure	193
Table 5.6	Permeate stream characteristics of the NF of the textile effluent using 440 Da MWCO hollow fiber membrane	195
Table 6.1	Characterization of the effluent from the textile plant	203
Table 6.2	Equilibrium analysis from Langmuir and Freundlich model ...	203
Table 6.3	Characterization of the effluent after adsorption	205

Table 6.4	Properties of the final effluent: NF after adsorption	207
Table 6.5	Properties of the final effluent: Direct NF	208
Table 6.6	Comparison of the performance of the two processes: Adsorption followed by NF (Proc. 1) and direct NF (Proc. 2)	208
Table 6.7	Characterization of the effluent from the textile plant	211
Table 6.8	Characterization of effluent after AOP which was used for NF ...	213
Table 6.9	Characterization of effluent at the end of AOP followed by NF	214
Table 6.10	Characterization of effluent at the end of double-stage NF	216
Table 6.11	Chemical structure and physical properties of the reactive dyes	218
Table 6.12	Values of Langmuir and Freundlich isotherm constants	219
Table 7.1	Comparison of different resistances with respect to the total resistance. Gel layer and the total resistances are at the end of the experiment	245
Table 7.2	Performance of chemical treatment I and II for a typical retentate	254
Table 8.1	Fractional coacervate phase volume and surfactant extraction data for some selective conditions for CPE of chrysoidine	261
Table 9.1	Comparison of surface to volume ratio	299
Table 9.2	Operating conditions for the EC of crystal violet dye	301
Table 9.3	Effect of different types of electrolyte on dye removal	305

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He has more than 12 years of experience in academics and research and published 135 papers in different reputed journals of importance. He has submitted 7 patents and was involved with 14 sponsored projects from various funding agencies. Dr. Purkait has guided 13 Ph.D. students and 7 are yet to get their Ph.D. degree.

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