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Aims and Scope

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):

- Environmentally benign chemical synthesis and processes (green catalysis, green solvents and reagents, atom-economy synthetic methods etc.)
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- Green chemical engineering processes (process integration, materials diversity, energy saving, waste minimization, efficient separation processes etc.)
- 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.

More information about this series at http://www.springer.com/series/11661

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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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Dr. Sourav Mondal has done his Ph.D. in Chemical Engineering from the Indian Institute of Technology Kharagpur. Presently he is working as a post-doctoral researcher in the University of Oxford. His research work is dedicated to various modeling and mathematical analysis of the transport phenomena in different separation processes including membrane-based filtration of wastewater treatment, fruit juice clarification, dye separation, bio-product separation, mixed matrix membrane filtration, etc. He is also working on modeling of adsorption, microfluidic mass transport, computational fluid dynamics of multiphase separation processes and other fluid dynamical processes as well as environmental challenges. He has been the recipient of Shastri Indo-Canadian research mobility award in 2012-2013 as a part of the scientific and innovative exchange program between the two nations. He has already authored two books, one book chapter, one patent, more than 30 publications in international journals of repute and presented at several international conferences.

Prof. Mihir Kumar Purkait is a Professor in the Department of Chemical Engineering at the Indian Institute of Technology Guwahati (IITG). Prior to joining as faculty in IITG, he has received his Ph.D. and M.Tech. in Chemical Engineering from the Indian Institute of Technology Kharagpur (IITKGP) after completing his B.Tech. and B.Sc. (Hons) in Chemistry from University of Calcutta. He has received several awards like: Dr. A.V. Rama Rao Foundation's Best Ph.D. Thesis and Research Award in Chemical Engineering from IIChE (2007), BOYSCAST Fellow award (2009–2010) from the DST, Young Engineers Award in the field of chemical engineering from the Institute of Engineers (India, 2009), and Young Scientist Medal award from the Indian National Science Academy (INSA, 2009). His current research activities are focused in four distinct areas viz.: i) membrane synthesis and separation technology (both ceramic and polymeric), ii) water pollution control, iii) smart material and iv) adsorption. In each of the areas, his goal is the synthesis of responsive materials and to develop a more fundamental understanding of the factors governing the performance of these technologies.

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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