FUNDAMENTALS OF POLYMER ENGINEERING

Second Edition
Revised and Expanded

Anil Kumar
Rakesh K. Gupta

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Anil Kumar
Indian Institute of Technology
Kanpur, India

Rakesh K. Gupta
West Virginia University
Morgantown, West Virginia, U.S.A.

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To the memory of my father.

Anil Kumar

To the memory of my father.

Rakesh Gupta

Preface to the Second Edition

The objectives and organization of the second edition remain essentially unchanged. The major difference from the first edition is the inclusion of new material on topics such as dendrimers, polymer recycling, Hansen solubility parameters, nanocomposites, creep in glassy polymers, and twin-screw extrusion. New examples have been introduced throughout the book, additional problems appear at the end of each chapter, and references to the literature have been updated. Additional text and figures have also been added.

The first edition has been successfully used in universities around the world, and we have received many encouraging comments. We hope the second edition will also find favor with our colleagues, and be useful to future generations of students of polymer science and engineering.

Anil Kumar
Rakesh K. Gupta

Preface to the First Edition

Synthetic polymers have considerable commercial importance and are known by several common names, such as plastics, macromolecules, and resins. These materials have become such an integral part of our daily existence that an introductory polymer course is now included in the curriculum of most students of science and engineering. We have written this book as the main text for an introductory course on polymers for advanced undergraduates and graduate students. The intent is to provide a systematic coverage of the essentials of polymers.

After an introduction to polymers as materials in the first two chapters, the mechanisms of polymerization and their effect on the engineering design of reactors are elucidated. The succeeding chapters consider polymer characterization, polymer thermodynamics, and the behavior of polymers as melts, solutions, and solids both above and below the glass transition temperature. Also examined are crystallization, diffusion of and through polymers, and polymer processing. Each chapter can, for the most part, be

read independently of the others, and this should allow an instructor to design the course to his or her own liking. Note that the problems given at the end of each chapter also serve to complement the main text. Some of these problems cite references to the literature where alternative viewpoints are introduced. We have been teaching polymer science for a long time, and we have changed the course content from year to year by adopting and expanding on ideas of the kind embodied in these problems.

Since polymer science is an extremely vast area, the decision to include or exclude a given subject matter in the text has been a difficult one. In this endeavor, although our own biases will show in places, we have been guided by how indispensable a particular topic is to proper understanding. We have attempted to keep the treatment simple without losing the essential features; for depth of coverage, the reader is referred to the pertinent technical literature. Keeping the student in mind, we have provided intermediate steps in most derivations. For the instructor, lecturing becomes easy since all that is contained in the book can be put on the board. The future will tell to what extent we have succeeded in our chosen objectives.

We have benefited from the comments of several friends and colleagues who read different parts of the book in draft form. Our special thanks go to Ashok Khanna, Raj Chhabra, Deepak Doraiswamy, Hota V. S. GangaRao, Dave Kofke, Mike Ryan, and Joe Shaeiwitz. Professor Khanna has used the problem sets of the first seven chapters in his class for several years.

After finishing my Ph.D. from Carnegie-Mellon University, I (Anil Kumar) joined the Department of Chemical Engineering at the Indian Institute of Technology, Kanpur, India, in 1972. My experience at this place has been rich and complete, and I decided to stay here for the rest of my life. I am fortunate to have a good set of students from year to year with whom I have been able to experiment in teaching various facets of polymer science and modify portions of this book continuously.

Rakesh Gupta would like to thank Professor Santosh Gupta for introducing polymer science to him when he was an undergraduate student. This interest in polymers was nurtured by Professor Art Metzner and Dr. K. F. Wissbrun, who were his Ph.D. thesis advisors. Rakesh learned even more from the many graduate students who chose to work with him, and their contributions to this book are obvious. Kurt Wissbrun reviewed the entire manuscript and provided invaluable help and encouragement during the final phases of writing. Progress on the book was also aided by the enthusiastic support of Gene Cilento, the Department Chairman at West Virginia University. Rakesh adds that these efforts would have come to nought without the determined help of his wife, Gunjan, who guarded his spare time and allowed him to devote it

entirely to this project. According to Rakesh, "She believed me when I told her it would take two years; seven years later she still believes me!"

I doubt that this book would ever have been completed without the constant support of my wife, Renu. During this time there have been several anxious moments, primarily because our children, Chetna and Pushkar, were trying to choose their careers and settle down. In taking care of them, my role was merely helping her, and she allowed me to divide my attention between home and work. Thank you, Renu.

Anil Kumar
Rakesh Gupta

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