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Keith T. O'Brien

Computer Modeling for Extrusion and Other Continuous Polymer Processes

Applications

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APPLICATIONS OF COMPUTER MODELING FOR EXTRUSION AND OTHER CONTINUOUS POLYMER PROCESSES

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COMPUTER AIDED ENGINEERING FOR POLYMER PROCESSING

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Computer Modeling for Polymer Processing

Editor: Keith T. O'Brien
Applications of
Computer Modeling for Extrusion
and Other Continuous Polymer Processes

Editor: Louis T. Manzione
Applications of
Computer Aided Engineering in Injection Molding

Foreword

The Society of Plastics Engineers is pleased to sponsor *Applications of Computer Modeling for Extrusion and Other Continuous Polymer Processes* edited by Keith T. O'Brien, Professor of Mechanical Engineering and Director of the Plastics Processing Laboratory, New Jersey Institute of Technology.

This volume completes the three-part series on *Computer Aided Engineering for Polymer Processing*. The preceding volumes are *Fundamentals of Computer Modeling for Polymer Processing* edited by Charles L. Tucker III of the University of Illinois at Urbana-Champaign, and *Applications of Computer Aided Engineering in Injection Molding* edited by Louis T. Manzione of AT&T Bell Laboratories.

This series provides the most comprehensive treatment of computer modeling of polymer processing to date. Editor for the entire series is Ernest C. Bernhardt, who also edited the first definitive volume on *CAE for Injection Molding* in 1983, and the first basic textbook on *Processing of Thermoplastic Materials* in 1959, both under SPE sponsorship.

SPE, through its Technical Volumes Committee, has long sponsored books on various aspects of plastics and polymers. Its involvement has ranged from identification of needed volumes to recruitment of authors. An ever-present ingredient, however, is review of the final manuscript to insure accuracy of the technical content.

This technical competence pervades all SPE activities, not only in publication of books but also in other activities such as technical conferences and educational programs. In addition, the Society publishes periodicals—*Plastics Engineering*, *Polymer Engineering and Science*, *Polymer Processing and Rheology*, *Journal of Vinyl Technology* and *Polymer Composites*—as well as conference proceedings and other selected publications, all of which are subject to the same rigorous technical review procedure.

The resource of some 37,000 practising plastics engineers has made SPE the largest organization of its type worldwide. Further information is available from the Society of 14 Fairfield Drive, Brookfield, Connecticut 06804, U.S.A.

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Computer Aided Engineering for Polymer Processing

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Ernest C. Bernhardt

Formerly with E.I. Du Pont de Nemours & Co., Inc., where he held positions in R&D, technical service and marketing management both in the US and in Europe, Dr. Bernhardt is the author of numerous publications and patents and editor of *Processing of Thermoplastic Materials* (Reinhold, 1959) and *Computer Aided Engineering for Injection Molding* (Hanser, 1983).

Dr. Bernhardt is a Fellow of the Society of Plastics Engineers and serves on the board of directors of its Injection Molding Division. He is a director of Plastics & Computer Inc., the company identified with the *TMconcept*® Expert System for Molding.

Computer Aided Engineering for Polymer Processing

Preface to the Series

Computer simulations have become an important tool for the engineering of polymer processing operations. They supersede the traditional trial-and-error methods that no longer are adequate to succeed in today's competitive environment.

The basic principles governing the processing of thermoplastic materials were established by the early 1950s. However, until recently, the complexity and sophistication of polymer process engineering have restricted its in-depth application to only the most critical problems.

Computer simulations offer the only practical means to apply the full capabilities of plastics engineering to optimize polymer processes. Computer modeling has become a requisite to assure the high levels of product quality and productivity demanded by industry in such diverse operations as injection molding, extrusion, calendering, mixing, devolatilization, etc.

This three-volume series on *Computer Aided Engineering for Polymer Processing* is the first unified presentation covering both the fundamentals of computer simulation of polymer processing as well as the industrial application of this technology. The contributors represent the pragmatism of industry as well as the theoretical knowledge of academia to provide a full and comprehensive coverage of the field.

The present volume on *Applications of Computer Modeling for Extrusion and Other Continuous Polymer Processes*, edited by Keith T. O'Brien, Mechanical and Industrial Engineering Department, New Jersey Institute of Technology, addresses problems faced by processing engineers concerned with the design and operation of continuous plastics processes ranging from extrusion to calendering, devolatilization, reactive processing, compounding, etc.

The companion applications-oriented volume of this series is *Applications of Computer Aided Engineering in Injection Molding*, edited by Louis T. Manzione, AT&T Bell Laboratories, published in 1987. It addresses the designers, processors and end-users of plastics parts and makes them aware of the broad choice of computer models that are at their disposal.

Both of the above applications-oriented volumes feature presentations by leading authors of commercial models and encourage the reader to compare and distinguish among the available software packages.

The volume on *Fundamentals of Computer Modeling for Polymer Processing*, edited by Charles L. Tucker III, Mechanical Engineering Department, University of Illinois at Urbana-Champaign, published in 1989, is directed primarily at developers of models for polymer processing. It presents the foundation of this series and is aimed to help engineers understand the mathematical methods used to create the process simulation programs that are described in the two applications volumes.

Montclair, New Jersey *Ernest C. Bernhardt*
January 1992

Preface to this Volume

Applications of Computer Modeling for Extrusion and Other Continuous Polymer Processes is a compendium of commercially available software packages, explaining their fundamentals and illustrating their capabilities and applications. The developers of the commercially available software were solicited through direct contacts and notices in major plastics processing periodicals and were asked to contribute chapters pertaining to their products.

The opening chapter discusses the scope of continuous polymer processes and serves as an introduction and guide to the presentations of the individual software packages that follow.

Chapters 2 through 10 treat these commercially available packages for modeling extrusion and other continuous processes. They are authored by those who wrote the programs or are engaged in their application. Each of the chapters emphasizes the capabilities of the programs and their practical implementation. This is achieved through the use of explicit examples and demonstrations. It should be noted that in addition to the software packages described herein, various companies have developed proprietary software for internal use, which could obviously not be included here.

Finally, the ultimate chapter anticipates developments over the next several years and envisions the likely course of simulation developments for continuous plastic processing operations. Many aspects of these operations have not yet received adequate analytical, or numerical, treatment. As a consequence, computer simulations are still restricted to specific sectors within the very broad spectrum of continuous plastics processing operations.

To reach a point in my career, where I felt competent to conduct the task of editing a book such as this, required the help and encouragement of many others. These include: Ernest Bernhardt (Plastics and Computer, Inc.), George Delancey (Stevens Institute of Technology), Bob Dix (BASF), Tom Dolce (Hoechst Celanese), Duncan Dowson (University of Leeds), Mel Druin (M. L. Druin and Associates), David Frostick (Thames Polytechnic), Costas Gogos (Stevens Institute of Technology), Jerry Kirshenbaum (Hoechst Celanese), Imrich Klein (Scientific Process and Research), John McVeigh (Brighton Polytechnic), Frank Mobbs (University of Leeds), John Parnaby (Lucas Industries), Dick Progelhof (University of South Carolina), Natti Rao (Consultant), Allan Serle (Hoechst Celanese), Harry Silla (Stevens Institute of Technology), Chris Taylor (University of Leeds), and Kurt Wissbrun (Hoechst Celanese). I would like to recognize them all along with the many others, too numerous to list.

My thanks are also extended to those who have funded my exploits including the Science Research Council, the Plastics Institute of America, the Foundation at New Jersey Institute of Technology, Hoechst Celanese Corporation, the Center for Manufacturing Systems, the Newark Section of the Society of Plastics Engineers, Allied-Signal Corporation, and the AT&T Foundation.

My gratitude is also expressed to my research students who have shared these exploits, particularly my doctoral candidates, Tzy-Cherng Jan and Chia-Ying Liu. Thanks go also to Ms. Evelyn Cirilo who helped with the administrative work. Finally, special thanks to Kay, Siobhan and Meghan for making the effort worthwhile.

Edison, New Jersey,
January 1992

Keith T. O'Brien

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