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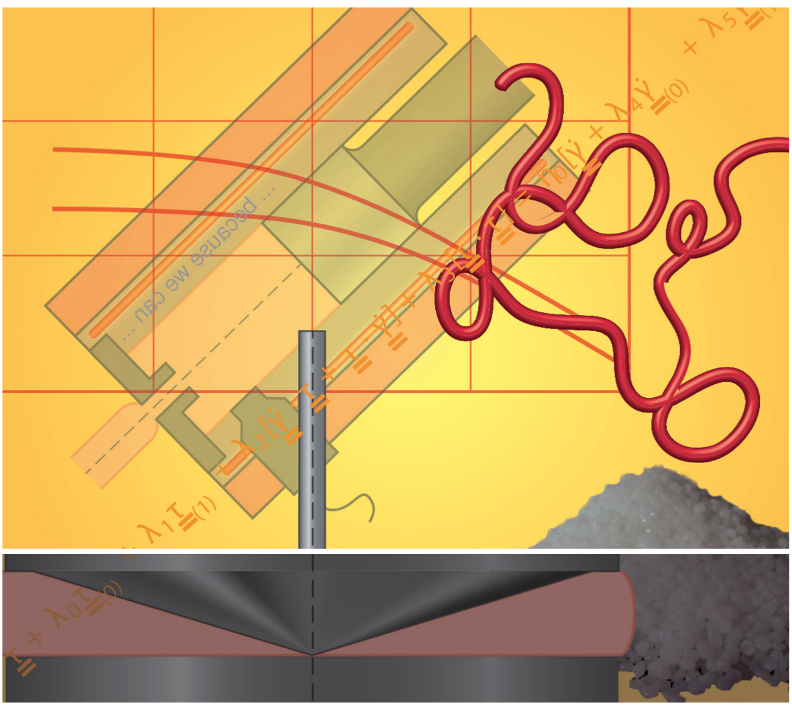
Polymer Rheology

Fundamentals and Applications



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Dedication

We dedicate this book to our friend, colleague, and mentor Professor Dr.-Ing. Dr. h.c. Gottfried W. Ehrenstein. His lifelong commitment to learning, teaching, and research has inspired more than a generation of students and engineers, and has resulted in a continuous flow of ideas and innovation in plastics technology.

Preface

Designed to provide a polymer rheology background to both engineering students and practicing engineers, this book is written at an intermediate level with the technical information and practical examples required to enable the reader to understand the complex rheological behavior of polymers and its far-reaching consequences. It also provides the necessary decision-making tools for the appropriate choice of rheological testing methods, and the means to troubleshoot rheology related problems encountered in polymer processing. The organization of Polymer Rheology – Fundamentals and Applications and the practical examples throughout the book make it an ideal textbook and reference book, and the information provided is particularly valuable to processors and raw materials suppliers.

The authors would like to acknowledge the invaluable help of many during the preparation of this manuscript: our colleagues at the Polymer Engineering Center at the University of Wisconsin-Madison and at the Institute for Polymer Technology at the Friedrich-Alexander-University in Erlangen, Germany. In particular we would like to thank Dr. Andrew Schmalzer for serving as a sounding board and for his input, John Puentes for helping with the example problems in Chapter 4, Chuanchom Aumnate for the measurements used in the examples in Chapters 2 and 5, and Camilo Perez for reviewing Chapter 3. We are grateful to Tobias Mattner for his outstanding job in not only drawing the figures, but also making excellent suggestions on how to more clearly present the information. Thanks are due to Dr. Christine Strohm for her valuable expertise in editing this book. Dr. Nadine Warkotsch, Dr. Mark Smith and Jörg Strohbach of Carl Hanser Verlag in Munich are thanked for their support throughout this project. Above all, the authors would like to thank their families for their continued support of their work and their input throughout the writing of this book.

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1 Introduction to Rheology

On December 9th of 1929, a little over a month after the Wall Street crash, and seven years after he published his book *Fluidity and Plasticity* [1], Eugene Bingham (Fig. 1.1), a chemistry professor at Lafayette College in Easton, Pennsylvania, and a group of chemists, engineers, and physicists met for the first time in Washington D.C.; they called themselves the *Society of Rheology*. Hence, for the first time the word rheology, coined by Markus Reiner and Eugene Bingham in 1920, was officially used[1].

Figure 1.1
Professor Eugene Bingham, in 1945 shortly before his death (Courtesy of Special Collections & College Archives, Skillman Library, Lafayette College)

1 The roots of the word rheology are the Greek "reo" (flow) and "logos" (study).

However, the history of the field of rheology goes back centuries prior to Bingham and Reiner. A historical review is not complete until the more important events and discoveries through time, and the people who made those events and discoveries possible, have been identified. In Table 1.1 we list these events, discoveries, and important publications. If we inadvertently left out some, we apologize.

Table 1.1 Historical overview of the field of rheology

When	Who	What	Ref
1663	B. Pascal	Published works on inviscid fluids	[2]
1678	R. Hooke	Published work on elastic springs	[3]
1687	I. S. Newton	Published work on viscous fluids	[4]
1705	Bernoulli brothers	Publish the Bernoulli equation	[5]
1807	T. Young	Proposes the elastic (Young's) modulus	[6]
1820	C. Navier	Describes behavior of Newtonian fluids which eventually becomes the Navier-Stokes equation	[7]
1822	A. Cauchy	Describes stress and strain and formulates the Cauchy deformation tensor	[7]
1829	S. Poisson	Describes Poisson's ratio, ν	[8]
1839	G. Hagen	Builds the first capillary viscometer	[9]
1840	J. L. M. Poiseuille	Studies the rheology of blood and builds a capillary viscometer	[10]
1845	G. G. Stokes	Formulates a three dimensional Newtonian fluid model	[11]
1849	G. G. Stokes	Studies the parabolic velocity distribution in a capillary	[5]
1851	G. G. Stokes	Sphere fall experiments	[12]
1859	A. V. Lourenço	Observes viscosity increase with an increase in molecular weight	[13]
1861	A. Lipowitz	Builds a penetrometer to measure the hardness of a gel with a sinking weight	[14]
1861	T. Graham	Coins the word "Colloid"	[15]
1867	J. C. Maxwell	Formulates the viscoelastic Maxwell model	[16]
1873	J. D. Van der Waals	Publishes work on intramolecular forces	[17]
1874	L. Boltzmann	Publishes the superposition principle	[18]
1876	L. Boltzmann	Publishes work on the memory function	[19]
1881	M. Margules	Derives equations that describe the viscosity in the shear flow between two concentric cylinders	[20]
1886	M. M. Couette	Derives equations that describe the viscosity in the shear flow between two concentric cylinders	[21]
1888	M. M. Couette	Builds the first concentric cylinder system to measure viscosity; the drag flow viscometer or the Couette device	[22]
1890	W. Thomson-Kelvin	Describes a "solid viscosity", meaning a viscoelastic solid, known today as the Kelvin model	[5]
1890	W. Voigt	Publishes experiments on viscoelastic solids	[23]
1891	W. Ostwald	Builds a capillary viscometer, Ostwald viscosimeter	[14]