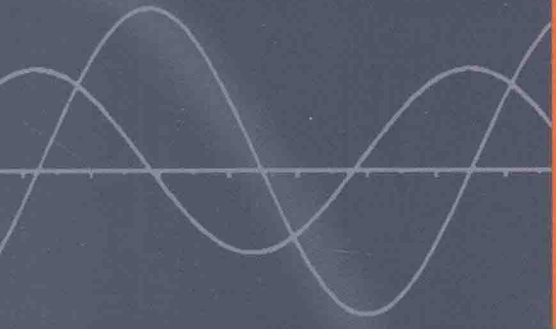
SPRINGER LABORATORY



R. Brummer

Rheology Essentials of Cosmetic and Food Emulsions

Springer

Rüdiger Brummer

Rheology Essentials of Cosmetic and Food Emulsions

184 Figures, 139 in color and 18 Tables

Springer

Rüdiger Brummer
Beiersdorf AG
Unnastr. 48
20245 Hamburg
Germany
e-mail: Ruediger.Brummer@Beiersdorf.com

Library of Congress Control Number: 2005930321

ISBN-10 3-540-25553-2 **Springer Berlin Heidelberg New York**
ISBN-13 978-3-540-25553-6 **Springer Berlin Heidelberg New York**

Springer is a part of Springer Science+Business Media
springeronline.com

Printed in Germany

Cover design: KünkelLopka GmbH, Heidelberg; *design&production*, Heidelberg, Germany
Typesetting and production: LE-TEX Jelonek, Schmidt & Vöckler GbR, Leipzig, Germany

2/3141 YL 5 4 3 2 1 0 - Printed on acid-free paper

Springer Laboratory Manuals in Polymer Science

Pasch, Trathnigg: HPLC of Polymers
ISBN: 3-540-61689-9 (hardcover)
ISBN: 3-540-65551-4 (softcover)

Mori, Barth: Size Exclusion Chromatography
ISBN: 3-540-65635-9

Pasch, Schrepp: MALDI-TOF Mass Spectrometry of Synthetic Polymers
ISBN: 3-540-44259-6

Kulicke, Clasen: Viscosimetry of Polymers and Polyelectrolytes
ISBN: 3-540-40760-X

Hatada, Kitayama: NMR Spectroscopy of Polymers
ISBN: 3-540-40220-9

Brummer, R.: Rheology Essentials of Cosmetics and Food Emulsions
ISBN: 3-540-25553-2

Mächtle, W.; Börger, L.: Analytical Ultracentrifugation of Polymers and Nanoparticles
ISBN: 3-540-23432-2

About the Author

Rüdiger Brummer is a physicist at Beiersdorf AG with research interests in pressure-sensitive adhesives and cosmetic emulsions. He has published several professional papers and is the holder of patents. He completed his physics degree at the Christian Albrecht University in Kiel. Beginning in 1978 he worked as a scientist in the basic research laboratory of the Dr. Beyschlag Company in Heide.

In 1981 he moved to Phoenix AG in Hamburg, where he worked in a development laboratory for metal–rubber materials and started programming with finite elements. After several years he joined Beiersdorf AG, where he started with rheological measurements. In 1991 he became head of the Rheology and Thermal Analysis Department at Beiersdorf AG in Hamburg.

Rüdiger Brummer is a member of the German Rheology Society and the American Society of Rheology. He is active in the German DIN for viscosity and in the IUPAC sub-committee Structure and Properties of Commercial Polymers.

Springer Laboratory Manuals in Polymer Science

Dedication

Dedicated to my paternal friend and physicist colleague
Dr. Gustav Richter

***Konfuzius** (551–479 BC)*
Humans have three ways to act intelligently:
First of all: by thinking – that is the noblest.
Secondly: by copying – that is the easiest.
Thirdly: by experience – that is the bitterest.

Foreword

In the last decade, technical progress has positively influenced the methods of dynamic mechanical analysis. At the same time, data handling has become more comfortable and much easier.

In this context it is not at all surprising that various techniques of rheology have opened up new insights into so far unknown and undiscovered structures.

Furthermore, new correlations between rheological behavior and specific product or structure properties have been revealed and are used for systematic investigations.

However, sound information about the proper use of rheological techniques is still weak. The majority of published information deals with the rheology of polymers. This book focuses on the rheology of dispersions and emulsions. Students, chemists, engineers and laboratory assistants working on these materials, will find in this book fundamental principles, how to apply rheology, and what kind of information can be obtained.

I wish all readers a lot of energy and enthusiasm for the opportunities offered by rheological techniques.

May 2005

Prof. Dr. Klaus-Peter Wittern
Corporate Vice President
University of Hamburg, Department of Chemistry

Preface

In the last 20 years, personal computers have become more and more powerful. As a result, dynamic mechanical analysis (DMA) has become more and more efficient and rheology has consequently become a common tool in the analytical laboratory. Modern rheometers today are three times cheaper than 10 years ago but four times better in performance. Now this technique and the powerful PC are more often employed by the non-specialist.

However, information on the use of this technique is still thinly scattered. There are several excellent books about rheology and many papers covering correlation with other techniques. Most of these describe polymers and only a few books refer to dispersions and emulsions. Still today you often hear the question: "What is DMA and what can it tell me about my product or process?"

This book attempts to give students, chemists, engineers, and laboratory assistants in the cosmetic field a starting point to understand where and how rheology can be applied. Therefore I have minimized the mathematics and statistics and have given information on how to use a rheometer. Rheology is an efficient tool for getting information on material behavior under different conditions and it can be done very cost effectively when done properly.

Hamburg, May 2005 Rüdiger Brummer

Acknowledgements

I have so many people to thank for their help and support; more than I can list here. First of all, I would like to thank Prof. Kulicke for his suggestion and Prof. Wittern for his encouragement to write this book. They gave me the motivation for this project.

Special appreciation is expressed to my colleagues in the Rheology and Thermo Analysis Laboratory – Frank Hetzel, Martin Griebenow, Rüdiger Uhlmann, Volker Schlesiger and Angelika Wiese – for their collaboration and careful preparation of all the test specimens, since all measurements were done in our laboratory.

I would also like to thank all the students who finished their studies in my laboratory, especially Dr. Thorsten Berg, Dr. Sybille Friedrich and Dipl. Ing. Mandy Mühl, for their dedication and the results of their work, some of which I was able to use in this book.

For the micrographs I would like to thank Dr. Roger Wepf and his coworkers at Beiersdorf. All other figures were taken from the manual of the rheometer supplier, or from internet portals, or are my own.

Finding the best English words was the task of Dr. Marcia Franzen-Hintze, who showed a great propensity to understand my point of view on rheology.

I am also grateful to Prof. Werner-Michael Kulicke and Dr. Christian Clasen, who were kind enough to review this manuscript.

Special thanks go to my friend and fellow rheologist, Dr. Bernhard Hochstein, for stimulating discussions while interpreting the data and for his help in reviewing the formulas.

Last but not least, I would like to thank my family and especially my wife, who was so tolerant and understanding while I was writing, revising and correcting this book on holidays, weekends, evenings, etc.

Hamburg, May 2005 Rüdiger Brummer

List of Symbols

A	Space	m^2
b	Mean droplet diameter	m
c	Concentration	$mol\,l^{-1}$
C_1, C_2	Coefficient	–
d	Diameter	m
$d_{v,10}$	10% of the volume diameter	m
$d_{v,50}$	50% of the volume diameter	m
$d_{v,90}$	90% of the volume diameter	m
E_A	Activation energy	$J\,mol^{-1}$
E/m	Energy input	$J\,kg^{-1}$
F	Force	N
G_E	Modulus of an ideal elastic solid	Pa
G^*	Complex modulus	Pa
G'	Storage modulus	Pa
G''	Loss modulus	Pa
G_p	Plateau modulus	Pa
$G_{1\,rad/s}$	Storage modulus at $\omega = 1\,rad/s$	Pa
h	Thickness	m
I	Current	A
L	Length	m
M	Molecular weight	$g\,mol^{-1}$
M_{cp}	Torque for cone plates	$N\,m^{-1}$
M_{pp}	Torque for parallel plates	$N\,m^{-1}$
n	Revolutions per minute	rpm
p	Pressure	Pa
p_1	Intake pressure	Pa
p_2	Outtake pressure	Pa
Q	Volume per time	$m^3\,s^{-1}$
R	Radius	m
Re	Reynold number	–
r	Radius	m
t	Time	s
T	Temperature	°C
T	Absolute temperature	K

U	Voltage	V
v	Speed	$m\,s^{-1}$
$\dot{V}$	Volume per time	$m^3\,s^{-1}$
w	Characteristic rate	s^{-1}
$\overline{x}$	Average length	m
β	Angle	°
δ	Phase angle	°
η	Dynamic viscosity	Pa s
η_{rel}	Relative viscosity	Pa s
λ	Wavelength	m
ϱ	Density	$kg\,m^3$
γ	Deformation	%
$\dot{\gamma}$	Shear rate	s^{-1}
τ	Shear stress	Pa
τ_{yield}	Yield stress	Pa
τ_i	Relaxation time	s^{-1}
ν	Cinematic viscosity	$m^2\,s^{-1}$
ω	Frequency	$rad\,s^{-1}$

List of Abbreviations

ASTM	American Society for Testing Materials
cmc	critical micelle constant
DAB	Deutsches Arzneibuch
DIN	Deutsche Industrie Norm
INCI	International Cosmetic Ingredients Dictionary
ISO	International Organization for Standardization
JSA	Japanese Standards Association
NMR	Nuclear magnetic resonance
PFGSE	Pulsed-field gradient spin echo
PGPH	Polyglyceryl-2-dipolyhydroxystearate
Re	Reynolds number
TEM	Transmission electron microscopy
TGI	Polyglyceryl-3-diisostearate
UWG	Gesetz gegen den unlauteren Wettbewerb
LBMG	Lebensmittel- und Bedarfsgegenständegesetz
HWG	Heilmittelwerbegesetz
MBO	Musterberufsordnung der Deutschen Ärzte

Table of Contents