MODERN COATING AND DRYING TECHNOLOGY

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Library of Congress Cataloging-in-Publication Data

Modern coating and drying technology / editors,
Edward D. Cohen and Edgar B. Gutoff.
p. cm.—(Interfacial engineering series)
Based on a 2-day course organized for the AIChE Spring National Meeting in Orlando, Fla., Mar. 1990, held in conjunction with the Fifth Biennial International Symposium on the Mechanics of Thin Film Coating.
Includes bibliographical references and index.
ISBN 1-56081-097-1
1. Coating—Congresses. 2. Drying—Congresses. I. Cohen, Edward D. II. Gutoff, Edgar B. III. Series.
TP156.C57157 1992
667'.9—dc20 92-7737
CIP

British Library Cataloguing in Publication Data

Modern Coating and Drying Technology.—(Interfacial Engineering Series;v.1)
I. Cohen, Edward D. II. Gutoff, Edgar B.
III. Series
667

ISBN 3-527-28246-7

Printed in the United States of America

ISBN 1-56081-097-1 VCH Publishers
ISBN 3-527-28246-7 VCH Verlagsgesellschaft

Printing History:
10 9 8 7 6 5 4 3 2 1

Published jointly by:

VCH Publishers, Inc.
220 East 23rd Street
Suite 909
New York, NY 10010

VCH Verlagsgesellschaft mbH
P.O. Box 10 11 61
D-6940 Weinheim
Federal Republic of Germany

VCH Publishers (UK) Ltd.
8 Wellington Court
Cambridge CB1 1HZ
United Kingdom

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INTRODUCTION

This book introduces coating technology to those interested in learning about this vast and fascinating subject. It is a response by the authors to the question asked by engineers, chemists, and physicists new to certain areas of the field, "How do I learn about coating?" Many recent texts are available to guide the novice to other major technologies, such as heat and mass transfer, statistics, grinding, or photographic science, but no basic reference offers an introduction to the science of coating. This volume is intended to meet that need.

Realizing the difficulty of finding an easy access to coating information, the authors presented a two-day course in conjunction with the 1990 American Institute of Chemical Engineers (AIChE) Coating Symposium. An unexpectedly large attendance of engineers confirmed the demand for the course and the value of publishing this material.

It is important to begin by defining what we mean by "coatings" and "coating industry." The term coating is used in many ways and applied to the material used as well as the process. We define coating as the process of replacing air with a new material on the substrate. The focal areas are replacement, which is the coating engineering process, and the material doing the replacing. Together they comprise the "coating industry."

A quick look at this rapidly growing industry can be as deceptive as viewing the tip of an iceberg. The best known part—the ten percent of the iceberg visible above the water—includes the wide variety of paint and protective films used to brighten and protect cars, houses, or bridges by covering their underlying construction so that it retains its integrity and stays useful. In the United States this segment of the coatings industry has a value of $14,700,000,000.

The rest of the coatings industry is less visible. We seldom think of these applications as coatings although they play a key part in our daily lives. The entire publishing industry, for example, is based on coatings. The page you are reading has been coated to give it the needed gloss, strength, and ink acceptability. Lithographic printing plates used in printing presses consist of photosensitive coatings on aluminum. Photographic film is a coated product used to expose the plates, set the type, and prepare the printed pictures. The actual printing process coats the paper with ink to give the desired images.

In one sense, coating technology also forms the basis for the entertainment industry. Audio and video tapes are made of magnetic particles dispersed in a binder and then coated on a

polyester base. The base itself has been coated to improve the adherence of the magnetic layer. Color film consisting of many layers of coatings is used extensively to produce the images we watch in the cinema and color photographs.

Coating is a prime technology used in the computer industry. Magnetic-coated structures, such as Winchester hard drives and floppy disks, store all the information processed by computers. The development of processes capable of making these magnetic devices inexpensively and with the necessary precision helped spur the growth of the computer industry. Coated products, such as photoresist films, are used to fabricate circuit boards, and coatings connect the components in them. Coated optical disks are used for information storage and retrieval in computers as well as in the entertainment industry.

Adhesives coated on a wide variety of supports create many different products, such as adhesive and decorative tapes, envelopes, and labels. Adhesives coated onto nails improve their ability to bind to wood.

Coating also is one of the core technologies in the electrostatic copier industry. Efficient and safe coating of the selenium drums and transfer of toners from the exposed drum to the paper represent key steps in the copying process.

A partial list of coatings industries and their dollar production (Table P1) shows the economic importance of this industry. Its total dollar value of over $340,000,000,000 far exceeds the value of the paint and surface coatings industry alone.

Coating started to come into its own as a stand-alone unit operation in the early 1970s when Professor L. E. Scriven at the University of Minnesota formed a research group to study coating flows. By the early 1980s this group pioneered the development of flow visualization methods and computer-based theoretical modeling technology needed to start the unification process. Coating research now takes place at several other universities worldwide and in major corporations where coating is a core technology. Major advances have been made in understanding and theoretically predicting coating flows, as well as in the development of unique precision applicators capable of coating at high line speeds. Similar developments are now underway in drying and curing of coatings.

The American Institute of Chemical Engineers (AIChE) also has taken a leading role in developing the study of coating. Biennial AIChE symposia on the Mechanics of Thin Film Coating, which originated in 1982 at the spring national meeting in Orlando, Florida, have served as an international focus for coating research. Attendance has subsequently grown to 350 participants at the 1990 symposium. At that meeting, 66 technical papers were presented at seven sessions.

Examining a list of the nearly 100 companies and schools that sent engineers to the 1990 symposium provides an interesting way to view the scope and areas of interest of today's coating industry and research and short courses. Table P2 identifies many of them; Table P3 gives the session topics and some paper titles.

TABLE P1. / Coating Industry Partial Value.

Industry Segment Reference	*SIC Code*[1]	*$ Value in Millions*[2]	*Reference*
Paints and Coatings	2851	14,658	Reynolds[3]
Adhesives and Sealants	2891	5,462	Reynolds[3]
Printing and Publishing	27	168,514	Reynolds[3]
Paper			
Sanitary Food Containers	2656	2,282	Reynolds[3]
Bags Plastic Laminated and Coated	2673	5,215	Reynolds[3]
Papers Coated and Laminated	2671	2,672	Reynolds[3]
Papers Coated and Laminated	2672	5,355	Reynolds[3]
Photographic Films Worldwide		25,000	Wolfman[4]
Inorganic Coatings Europe		1,000	Frost[5]
Magnetic Media			
Floppy Disks		12,400	Stambler[6]
Standard Magnetic Disks		258	Cohen[7]
TOTAL		247,967	
Electronics			
Printed Circuit boards	3672	5,151	Reynolds[3]
Prerecorded Music		8,020	Reynolds[3]
Household Audio and Video	3651	6,708	Reynolds[3]
Computers and Peripherals		72,500	Stambler[6]
TOTAL		92,379	

[1]SIC is standard industrial classification.
[2]Values shown are estimate for 1990 in 1987 dollars.
[3]P. J. Reynolds, 1990, *United States Industrial Outlook*, Report prepared for the Bureau of Industrial Economics by the U.S. Department of Commerce. Washington, D.C.: U.S. Government Printing Office.
[4]A. and L. Wolfman, 1989, *Wolfman Report on the Photographic Industry in the U. S.* New York: Diamandis Communications.
[5]Frost and Sullivan Market Report E1112, 1989, *Inorganic Coating Market in Western Europe*. New York: Frost and Sullivan.
[6]A. Stambler, 1986, Floppy magnetic discs, sale for microcomputers, *Tech. Fore.* 10:5.
[7]A. Cohen, 1988, *Elect. Busns.* 14:76.

Another example of the growing focus on coating can be seen in the Center for Interfacial Engineering, organized at the University of Minnesota in 1988 as a National Science Foundation Engineering Research Center. Coating Process Fundamentals is one of its core programs, and several of its other research areas deal directly with interfacial phenomena present in coating.

The Center's Coating Process Fundamentals program has responded to the need for more formal education and training in coating. Undergraduate and graduate level courses are given in coating, rheology, and interfacial phenomena. In addition two short courses in coating technology, an introductory course "Topics in Coating and Drying Technology" and an advanced course "Coating Process Fundamentals" are offered to meet the needs of industrial scientists. Because the editors and two of the authors of this book are closely associated with Professor L. E. Scriven, who heads this program, we decided to issue this book as part of the Center for Interfacial Engineering textbook series.

TABLE P2. / Companies in Attendance 1990 AIChE Thin-Film Symposium.

3M Company
3M-Italia
Agfa-Gevaert
Air Products
Akzo Research
Alcoa Technical
Ampex Corporation
Anitec Image Corporation
Aristech Chem. Corporation
Asia Chemical Corporation
AT&T Bell Laboratories
Avery International
BASF AG
Bayer AG
Beloit
Black Clawson
Boehringer Mannheim
California Institute of Technology
Case Western University
Dai Nippon Printing
Dow Chemical
Drexel University
DuPont
Eastman Kodak
Exxon
Florida Institute of Technology
Ford Motor
Fuji Photo Film
General Electric
Hoechst AG
IBM
Ilford AG
James River
Ind. Technical Research Institute, Taiwan
Konica Corp
Lawrence Livermore National Laboratories
Leeds University
Mead Imaging
M. I. T.
Miles, Inc.
Mobil Chemical
National Tsing Hua Univ.
North Dakota State Univ.
Polaroid
Polychrome
PPG Industries
Pre-Finish Metals
Rennselaer Polytechnic Inst.
Rexham
Rohm & Haas
Rutgers
Sandia National Laboratory
Sherwin-Williams
SUNY Buffalo
Sumitomo/3M Ltd.
The Glidden Co.
Tandy Magnetic Media
The Institute of Paper Science
Typon
Università di Cagliari
Universiteit Antwerpen
University of Arkansas
University of California
University of Minnesota
University of Missouri-Rolla
University of Notre Dame
University of Saskatchewan
University of Tulsa
VEB Filmfabrik Wolfen
W. L. Gore & Assoc.
W. R. Grace
Western Michigan Univ.
W. Troller & Co. AG
Xerox

The book is based on presentations given during "Technology of Thin Film Coatings," a two-day course organized by one of the editors, Edgar B. Gutoff, for the AIChE Spring National Meeting in Orlando, Florida, in March, 1990, held in connection with the fifth biennial International Symposium on the Mechanics of Thin Film Coating. Individual chapters were written by experts in the fields within the broad area it covers. While the authors of previous texts on coating, such as George Booth (1970),

TABLE P3. / Areas of Chemical Engineering Activity in Coating.

Session Headings and Some Paper Titles at the 1990 AIChE Symposium on Mechanics of Thin Film Coating

Dynamic Wetting and Interfacial Phenomena
- Physics of dynamic wetting and air entrainment
- Coating the inside of a capillary with a square cross section

Advanced Materials and Coating Additives
- Fundamentals of sol-gel coating
- Scanning tunneling microscope characterization of spin-coated polystyrene
- A new technology for the formation of high-solids metallic finishes

Computational Methods
- On modeling the effects of polymer additives in coating flows
- Nonlinear theory of squeeze coating

Operation and Optimization of Coating Process
- Analysis of curtain coating flow
- Experimental study of multilayer slide coating with shear thinning liquid
- Thin film coating with knife or blade

Leveling and Drying
- Evaporation of thin films formed by dip coating
- "Starry night" and drying
- Coating and leveling of thin organic layers in the microelectronics industry

Stability of Free Surface Flows
- Experimental verification of the calculated frequency response of a multilayer slide coating
- Fundamental studies of slot coating
- The effect of shear thinning fluids and the use of dimensional analysis

Herbert Weiss (1977), and Donatas Satas (1984), are connected with the paper and converting industry, five of our six authors are associated with the photographic industry.

In this book we have tried to cover the major processes used in coating continuous webs—from fluid preparation and delivery through coating application and drying to the finished product—in a way that explains the whys and wherefores of the process. We focus on the entire process, not just the application hardware, because all factors from web vibration to removal of bubbles must be understood to produce a finished saleable coating product. The book gives particular attention to the precision application technology needed to produce high performance coatings, such as those used to manufacture magnetic tape and photographic film, because this area has become very important since previous coating books were issued and is one that will continue to grow in the future.

We discuss limitations in the speed or thickness of the coating, causes of various defects that occur, handling of the web or support, drying of the coated web, and ways in which the surface chemistry of both the coating fluid and the coating support affect the process. Nevertheless, the book could have been called "Selected Topics in the Coating and Drying of Webs" because it does not cover every coating operation. The chapters on fluid preparation web handling, and drying are applicable to most processes. The chapter on roll coating goes into detail only on reverse, forward roll, and gravure coating and instabilities that occur in those operations. Of the many other roll coating

operations, air knife coating occupies a separate chapter while dip and screen coatings are not discussed.

The chapter on premetered coating covers slot, slide, and curtain coating, and the effects of surface chemistry on these processes. It discusses in detail the maximum speed of coating and the minimum coverage that can be coated. Electrostatic coating, vacuum coatings, spin coating, spray coating, and powder coatings, however, are not touched upon in this text, nor do we mention fiber and wire coatings, such as coating insulation on copper wires, or protective coating on glass optical fibers. Web handling and drives receive a thorough treatment, just as drying does, but curing by ultraviolet or electron beam radiation does not.

Acknowledgments

The authors gratefully acknowledge the contributions of Dr. Hertha Schulze of the University of Minnesota Center for Interfacial Engineering (CIE) in the production and issuing of this volume. Without her efforts this book would not have been completed. The encouragement and support of the CIE and its director, Dr. D. Fennell Evans, to undertake and complete this work is also gratefully acknowledged.

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