Fourth Edition

ORGANIC COATINGS

Science and Technology

Frank N. Jones • Mark E. Nichols • Socrates Peter Pappas

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THE DEFINITIVE GUIDE TO ORGANIC COATINGS, THOROUGHLY REVISED AND UPDATED—NOW WITH COVERAGE OF A RANGE OF TOPICS NOT COVERED IN PREVIOUS EDITIONS

Organic Coatings: Science and Technology, Fourth Edition offers unparalleled coverage of organic coatings technology and its many applications. Written by three leading industry experts (including a new, internationally-recognized coatings scientist), the fourth edition presents a systematic survey of the field in which material from the previous edition is revised and updated. The fourth edition also features new or additional treatment of such topics as superhydrophobic, ice-phobic, antimicrobial, and self-healing coatings; sustainability, artist paints, and exterior architectural primers. making it even more relevant and useful for scientists and engineers in the field, as well as for students in coatings courses.

The book incorporates up-to-date coverage of recent developments in the field with detailed discussions of the principles underlying the technology and their applications in the development, production, and uses of organic coatings. All chapters in this new edition have been updated to assure consistency and to enable extensive cross-referencing. The material presented is also applicable to the related areas of printing inks and adhesives, as well as areas within the plastics industry.

This new edition:

- Completely revises outdated chapters to ensure consistency and to enable extensive cross-referencing
- Correlates the empirical technology of coatings with the underlying science throughout
- Provides expert troubleshooting guidance for coatings scientists and technologists
- Features hundreds of illustrative figures and extensive references to the literature
- A new, internationally-recognized coatings scientist brings fresh perspective to the content.

Providing a broad overview for beginners in the field of organic coatings and a handy reference for seasoned professionals, *Organic Coatings: Science and Technology, Fourth Edition*, gives you the information and answers you need, when you need them.

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Organic Coatings

Zeno W. Wicks, Jr., 1920–2007

Zeno was the lead author of the first three editions of this book. Two of us (Jones and Pappas) remember him fondly as an outstanding scientist, a charismatic teacher, a mentor, a marvelous colleague, and a gentleman. Zeno influenced hundreds, more likely, thousands, of students, many of whom have made careers in coatings. His favorite advice to them was "Don't park your brains at the door."

Being in a younger generation, Mark Nichols missed out on meeting Zeno. "My loss," he says, and he is right.

Zeno got his Ph.D. in Chemistry at the University of Illinois. He joined Inmont Corporation, where he advanced to vice president of research and development during a 28-year career. (Inmont was a leading coating and ink producer, acquired by BASF in 1985.) For the next 11 years, he was professor and chair of the Department of Polymers and Coatings at North Dakota State University (NDSU). He then became a consultant. Among other activities, he traveled worldwide to teach about coatings. He received the Mattiello Memorial Award, the Roy W. Tess Award, and four Roon Awards.

Zeno was the best teacher we ever saw. He could teach all day, and when he invited a class to return after dinner for optional discussion, they came. This book originated as a set of lecture notes Zeno prepared during his last year at NDSU, where he taught a full-year course in coatings for upperclassmen and graduate students. He thought, rightfully so, that the notes might be helpful to his successors.

Preface

Coatings science and technology advance in a continuous stream of improvements with an occasional breakthrough. This year's house paint may look the same as that of 10 years ago, but it is a lot better. Thus, it is time to revise the third edition of *Organic Coatings: Science and Technology*, published in 2007. Here, the third edition has been completely updated. Our purpose remains the same—to provide a reference and textbook that interrelates coatings technology with current scientific understanding.

For the fourth edition, Mark Nichols joined the team of authors. For the first time, we have a real materials scientist involved—and a very good one. As editor-in-chief of the *Journal of Coatings Technology and Research*, Mark has a broad view of contemporary coatings technology and is a leading authority on automotive coatings. His contributions are reflected in major revisions. Entire books could be written about the subject of each chapter, and many have been. To be as comprehensive as possible in the limited space available, we have summarized each topic and have provided references for readers seeking more detailed information. We have striven to enhance the usefulness of this edition both as a classroom textbook on coatings science and as a reference book. The reader will benefit from having taken college level chemistry courses through organic chemistry, but no coursework in polymer or materials science is assumed.

Some chapters include brief descriptions of coating compositions and applications, supported by references, which could be omitted in a classroom or used for outside-of-class assignments, such as term papers. We hope that these specific examples enhance the value of the volume as a reference book and self-teaching text. We understand that the first three editions were widely used for this purpose. We have also defined the jargon of coatings to help newcomers to the field understand its specialized language. While this book is written specifically about coatings, many of the principles apply to the related fields of printing inks, adhesives, and parts of the plastics industry.

Coatings technology evolved empirically by trial and error. Directions on how to make and apply paint have been published for at least 2000 years. Since about 1900, scientific understanding of the applicable principles has evolved. In 1905 Einstein published an equation applicable to flow of pigmented paints, and before 1920, pioneers such as H. A. Gardner, E. Ladd, C. B. Hall, and M. Toch applied scientific methods to testing. However, the coatings field is extremely complex, and scientific understanding remains incomplete. Empirical formulation and experimentation is still essential in developing and using coatings. The often conflicting needs for sustainability, reduced impact on the environment and health, reasonable cost, and improved coating performance require continuing innovation. Our conviction is that understanding the underlying science can help formulators work more effectively and that an appreciation of the formulators' craft is essential for scientists and engineers working in the field. Knowledge should flow both ways.

A complete literature review for each chapter would fill much of the book. We only cite key references and those that support specific information. Many of the references in older editions were replaced with newer ones, but many old references remain because they describe significant contributions to the evolution of coatings technology. Various sources of additional information are available to investigators. These include refereed journals such as the *Journal of Coatings Technology and Research* and *Progress in Organic Coatings*, as well as books, trade journals, conference proceedings, academic dissertations, internal company reports, and information from suppliers and customers. Patents are sometimes overlooked, but they often include informative reviews of the "state of the art" and specific examples including formulas, test procedures, and results. Patents are also free and readily searchable online.

We thank Dean Webster and Carole Worth for their editorial assistance and helpful suggestions.

Contents

Chapter 1

Introduction to Coatings

Coatings have been used since prehistoric times to protect objects and convey information, and they are ubiquitous in modern society as they serve to both protect substrates and impart aesthetic qualities to improve objects' appearance. If you are reading this text in a traditional paper book, the paper is coated. Look up and the walls of your room are coated, as are the windows. If you are wearing glasses, the lenses are likely coated to improve the plastic's scratch resistance and absorb UV radiation. If you are reading this text on a computer screen, the screen is coated to prevent glare and perhaps reduce fingerprints. The CPU inside your computer exists because of coatings used during the printing of nanometer-sized circuits. If you are outside, the buildings, cars, airplanes, roads, and bridges are all coated. Objects without coatings are less common than those with coatings!

Just because coatings science is an ancient technology does not mean that innovation has ceased. Today many coatings scientists and formulators are working diligently to improve the performance of coatings, reduce the environmental impact of their manufacture and application, and create coatings that provide functionality beyond today's coatings.

1.1 DEFINITIONS AND SCOPE

Coatings are typically thought of as thin layers that are applied to an object, which is often referred to as the *substrate*. Thus, one of the defining characteristics of a coating is its thinness. While the thickness of a coating depends on the purpose it serves, typical coating thicknesses range from a few microns to a few hundred microns, but of course, exceptions to this are common. Historically, the thickness of a coating was often quoted in terms of mils, where 1 mil equals one thousandth of an inch or 25.4 μm.

While coatings can be made from any material, this book is primarily concerned with organic coatings. Thus, we leave for other books coatings such as the zinc coatings used to galvanize steel, ceramic coatings that are formed from metal oxides or when metals such as aluminum are anodized, and the many other inorganic coatings used to impart hardness, scratch resistance, or corrosion protection. While these coatings are both technically and economically important, they lie mostly beyond the scope of this book.

Organic coatings are often composite materials in that they are composed of more than one distinct phase. The matrix, called the *binder*, holds the other components of the coating composition together and typically forms the continuous phase in the dry coating. As stated previously, we are mostly concerned with organic coatings, where the binder is typically an organic polymer.

A confusing situation results from multiple meanings of the term *coating*. As a noun *coating* is used to describe both the material (usually a liquid) that is applied to a substrate and the resultant "dry" film. As a verb, *coating* means the process of application. Usually, the intended meaning of the word coating can be inferred from the context. The terms *paint* and *finish* often mean the same thing as *coating* and also are used both as nouns and verbs. What is the difference between a coating and a paint? Not much—the terms are often used interchangeably. However, it is fairly common practice to use "coatings" as the broader term and to restrict "paints" to the familiar architectural and household coatings and sometimes to maintenance coatings for bridges and tanks. Some prefer to call sophisticated materials that are used to coat automobiles and computer components "coatings," and others call them "paints." Consumers are often familiar with the terms *varnish* or *stain*. These are types of coatings that are used to protect and beautify wood

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and are certainly within the scope of this book as they are typically made from polymeric binders with or without pigments.

Because we are limiting the scope of this book to organic coatings that are historically associated with paints, we are also choosing not to cover important materials such as coatings applied to paper and fabrics, decals, laminates and cosmetics, and printing inks, even though one could argue that these coatings share much in common with traditional paints. However, readers interested in those materials will find that many of the basic principles discussed in this text are applicable to such materials. Restrictions of scope are necessary if the book is to be kept to a reasonable length, but our restrictions are not entirely arbitrary. The way in which we are defining coatings is based on common usage of the term in worldwide business. For classification purposes, coatings are often divided into three categories: architectural coatings, original equipment manufacturer (OEM) coatings, and special purpose coatings.

As the coatings industry is a relatively mature industry, its growth rate typically paces that of the general economy. Like many other industries, growth has slowed in North America and Europe and has dramatically increased in Asia and South America as those economies have boomed. An estimate of the value of coatings used in each region is shown in Figure 1.1. The total value of the global coatings market was estimated to be approximately $112 billion in 2014 (American Coatings Association and Chemquest Group, 2015).

Figure 1.2 summarizes the estimated value and volume of coating shipments in the United States for a recent 10-year period. The effect of the economic downturn in 2008–2009 is evident (Data from American Coatings Association and Chemquest Group, 2015).

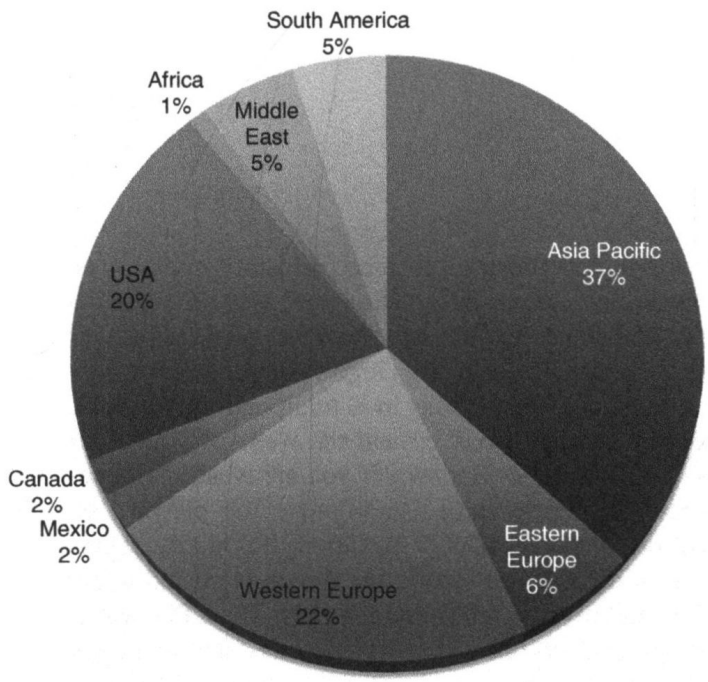

Figure 1.1 The value of coatings used in 2014. Source: Reproduced with permission of American Coatings Association.

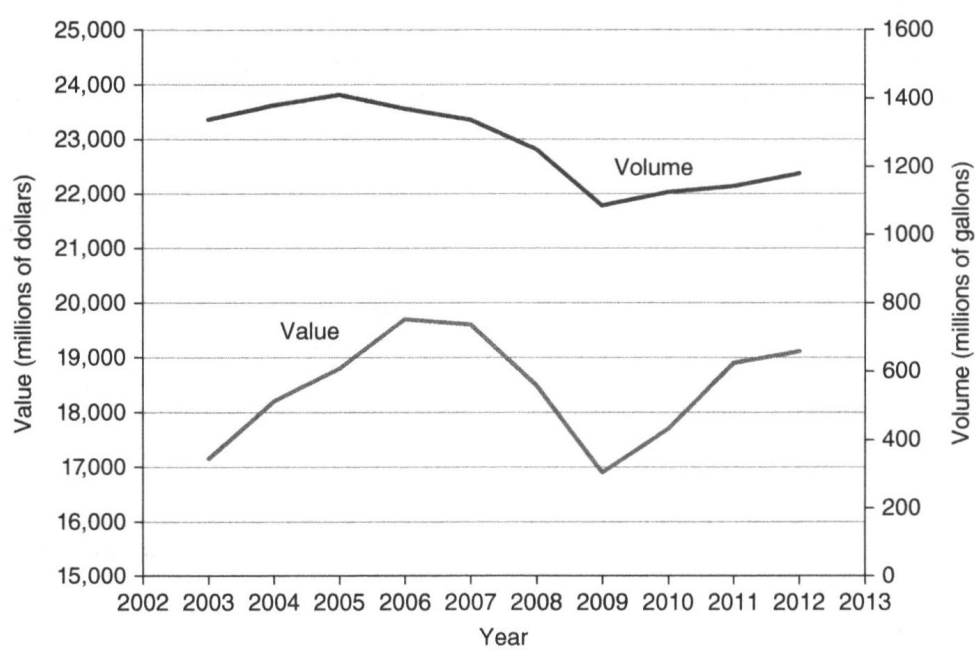

Figure 1.2 Ten-year trend in coating shipments in the United States (both gallons and dollar value). Source: Reproduced with permission of American Coatings Association.