INTRODUCTION

The occurrence of defects in the coating process is an ongoing concern to all who operate a coating line. A low defect level and high quality level are essential to meet the needs of the customer and to ensure a profitable business. Defects have become a particular current concern as product quality standards are continually increasing. In many instances, a product defect level that was considered to be of salable quality in the recent past (five years or more ago) would not be acceptable in the current marketplace. In addition, a wide range of new technically complex products, such as fuel cell membranes, thin film batteries, solar cells, and RFID (radiofrequency identification) chips, are being developed and manufactured and have very high quality and reproducibility specifications. They require an improvement in coating line performance and technology to obtain a defect-free product. Additional examples of difficult or complex products are thin coatings applied to thin substrates, high-speed coatings, and multilayer coatings.

One result of this increased need to reduce defects is that the knowledge to troubleshoot and eliminate defects on a coating line is an essential skill that all personnel must have to ensure success in eliminating the many different defects that can and do occur. The intent of this book is to provide the technology, procedures, and skills that are necessary for all personnel to effectively troubleshoot coating defects. The focus is on practical useable technology and procedures.

The definition of defects is a very important starting place for the discussions on troubleshooting defects that are in the following chapters. It is essential that all have the same understanding of what constitutes a coating and drying defect. The dictionary definitions of a defect are:
The lack of something necessary or desirable, a deficiency
An imperfection that impairs worth or utility
A deficiency

However, for our purpose the best definition is: “anything in the coating and drying process that results in customer dissatisfaction.” Typically, the common usage of a coating and drying defect refers only to a physical imperfection in the coating or substrate such as spots, repellents, chatter, or streaks. However, this new definition gives a more accurate view of defects and quality concerns that can arise in the web coating process. It also gives a better indication of the improvement opportunities in the coating and drying process. This new definition is used in this book.

This definition of coating and drying defects encompasses a wide variety of faults in the film and is not necessarily limited to the physical defects that were the focus of the first edition of this book. The range of defects covered by this definition are:

- Physical defects in the coated layer and in the substrate. Examples are bubbles, streaks, ribbing, air entrainment, contamination defects, chatter, wrinkles, comets, curl, condensation spots, and repeat marks.
- Deficiencies in the coating weights or thicknesses of the applied layer. There are several types of deficiencies affected by the coating process. The average coating weight must be at the required value for all of the rolls in a production run. The coating weight must also meet uniformity standards across the width of the web—the transverse direction or TD profile—and also along the length of the roll—the machine direction or MD profile. Transverse or machine direction variations can range from 1% to 10%, and a coating line designed for 10% will produce a defective product if 2% is needed.
- Deficiencies in product performance properties. These can be affected by variations in the coating and drying conditions. An example is the background density in silver halide films that is influenced by the drying conditions, which must be closely controlled to achieve desired levels. Adhesion of the coating to the substrate is influenced by the wetting of the coating on the substrate in the coating line. Haze and clarity of a coating can also be influenced by the process conditions. Many formulations are cured or cross-linked using either heat or ultraviolet radiation that will be influenced by the process.
- The inability to consistently obtain specified process conditions. If the location of the dry point, where the coating appears dry to the eye, is not maintained, then the product can be overdried, leading to poor product performance, or it can be underdried, leading to the product being wound with wet spots that will keep the wound roll stuck together and unable to be unwound. The latter can lead to reduced line speeds, resulting in higher costs and perhaps insufficient product to meet customer needs.

The elimination of defects is technically complex for several reasons. The current web coating line has many different process hardware elements and is technically sophisticated. Any of these process elements, starting with mixing the coating solutions, coating the substrate, drying the wet coating, unwinding and tracking the web, and winding the coated product, can introduce defects into the final product. Every raw material used can introduce defects.
Support equipment consists of the equipment and subsystems that are needed to sustain the effective operation of the major coater elements—the coating applicator, dryer, roll unwind, roll rewind, and web tracking. These secondary support systems can either lead to defects or can be used to eliminate them. In addition to the direct effect of a process element leading to defects, interactions between the different process elements can also lead to defects.

Another complication is that the defect does not necessarily appear in the same process step where it is created. Often the defect is observed several operations after it was created. A coating streak can be seen at the applicator. However, a mixing or contamination defect may not be seen until the product is coated and dried. A substrate defect may not be detected until the final product is wound or until it is slit into narrow widths to meet customer needs.

Additional complexities are that defects can and will occur at any stage in the product development cycle, starting with laboratory coatings and proceeding through the pilot plant for development coatings and finally through routine manufacture. There may be different defects at each stage, and eliminating them in the initial stage does not guarantee defect-free product in the next stage. A variety of different defects can be created that occur sporadically. A further complication is that similar appearing defects can have many causes and the cause may be different for each occurrence. Bubbles are a good example, since they can have a variety of causes, from air in the coating lines to boiling of solvents in the dryer. The defect cause can be simple, such as repeats from a dirt spot on a roll, or sophisticated, such as ribbing in roll coating or air entrainment in premetered coating.

Another source of defects can be in the inherent design of the coater and the capability of various hardware elements that make up the coating line. The coater may have been acceptable for the initial products for which it was designed. Changes in product composition and economic requirements can make the coater inadequate for current needs. In addition, the initial design is often a compromise and can have been built with some rate-limiting steps that become apparent as new products are produced and production rates are increased.

As a result of this complexity, a formal troubleshooting protocol or modus operandi is required to characterize the defect, identify its cause, and eliminate it. A random empirical approach will not be as effective, since it requires more time and resources than a formal approach and may not completely eradicate the defect or determine the true cause. This troubleshooting protocol includes several technologies to achieve a rapid, accurate, and cost-efficient solution. The components of this troubleshooting protocol are:

- A structured troubleshooting or problem-solving procedure.
- Analytical techniques to characterize the defect and the process elements in the coating line.
- The use of statistical methods to design necessary experiments and to analyze the data.
- A computer database to store all data and past experiences, which can be accessed by all personnel in the company.
- An understanding of how each of the process elements functions and what parameters in each system can lead to defects. Both a practical knowledge of the unit operation and a fundamental understanding of basic process mechanisms are needed to determine the causes of defect and to eliminate them.
The above protocol is a reactive program that is followed when defects are detected and need to be eliminated. The information gained from carrying out a successful troubleshooting procedure can also be used to prevent defects before they result in significant losses. Thus a similar structured but proactive protocol can be used to prevent defects and upgrade the process. It complements the reactive approach.

This book is organized to present a detailed discussion of each of the above steps of the protocol. Specific chapters are:

1. Introduction
2. Troubleshooting or Problem-Solving Procedure
3. Coater and Defect Analytical Tools
4. Problems Associated with Feed Preparation
5. Problems Associated with Roll Coating and Related Processes
6. Problems in Slot, Extrusion, Slide, and Curtain Coating
7. Coating Problems Associated with Coating Die Design
8. Surface Tension Driven Defects
9. Problems Associated with Static Electricity
10. Problems Associated with Drying
11. Problems Associated with Web Handling
12. The Role of Process Support Equipment
13. Coating Defects Databases
14. Defect Prevention