Coloring of Plastics

Second Edition

COLORING OF PLASTICS

Fundamentals
Second Edition

Edited by
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Contents

Preface

This publication represents the work of many people working in the color and appearance industry. Each one is regarded as most knowledgeable in the field they have covered in their chapters. Their contributions to the basic science of coloring plastics and other polymeric materials will serve industry for years to come.

Coloring of materials must start with an understanding of the basics of light, how light interacts with objects, and, finally, how humans react to and respond to the visible light reaching the eye and then interpreted by the brain. It should not be a surprise to anyone that no two people will see and interpret a colored object exactly the same. It is these variations and others that make the industry of coloring of plastics so interesting. The subjects in this publication have been designed to cover the most important technical and scientific issues involved in the coloring of plastic materials. This publication will be a valuable resource to those looking for information on the many aspects of plastics coloring.

This book covers our understanding of color as a science. It provides the foundation for many additional technological subjects. Measurement information along with matching, visually and instrumentally, will give the reader an understanding of the issues involved. Color specifications and a look at how statistical analysis can improve consistency, not only of colored polymer production runs but also of the colorants used to match the color, are addressed. The basic families of colorants are explained to give the reader an understanding of their properties. Basic information on the techniques usually employed to incorporate colorants into polymers as compounds or concentrates is presented. Environmental issues as well as issues of reuse of discarded materials are covered. An all-important issue, the potential interaction between colorants and other additives, is described to make the reader aware of potential problems with his or her projects. A diligent reader of this volume will come away with an enhanced appreciation of the technology, issues, potential problems, and considerations a colorist must consider if a plastics-coloring project is to succeed.

Volume 2 will cover polymers, by giving an overview of the major polymer issues. The differences between a commodity and an engineering (exotic) polymer will be discussed. The impact of these differences will influence the reader when evaluating a strategy for a coloring of plastic design. The other chapters in Volume 2 will describe the major polymer families. This description will cover such things as properties, advantages disadvantages, and typical markets and applications for the polymer families. This will be followed by general requirements for colorants in these polymers. Next, basic information will be given on methods normally used to incorporate colorants into these polymer. Special issues concerning the coloring of the polymers, including any particular problem or pitfalls that should be avoided are described. This should give the reader or researcher vital fundamental information that will help to avoid major upsets in a coloring project. An important additional piece of data given in each polymer chapter is a coloring matrix. This matrix lists the more important colorant chemical family types and their expected performance in the polymer under discussion. This fundamental information will supply information that will serve as a basic guideline to the reader, thus providing data which will help avoid a catastrophic failure involving the colorants used to color that specific polymer. This should be particularly useful to anyone approaching a coloring project using a polymer and/or colorants new to the reader. Basic attributes such as, but not limited to, colorant heat stability, physical properties, dispersability and any special issues connected to the colorant/polymer combination are covered.

Finally, one should not overlook the important issue that coatings and inks are polymers. It is quite possible the technical and process information contained here will also apply directly or indirectly to these associated polymeric materials. Therefore, this publication should have serious application capability to the coatings, ink and other related industries.

Robert A. Charvat

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This publication is dedicated to the authors and the many hours they committed to their work on each chapter. At the personal level, I thank the authors for responding cordially to my many calls and reacting professionally to my frustrations in completing this work. Also, a special thanks to my wife, Nancy, for her valuable assistance with the mechanics of good writing.

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CHAPTER 1

Introduction

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The goal of this textbook is to expose the reader to the many aspects of coloring of plastics. To accomplish this objective, the technologist must understand colorants for what they are and what they are not. He or she must understand the performance of colorants not only during the processing and manufacturing steps but also during the life cycle of the final product. Today it is important to consider the issues of recycling the product after its useful life has come to an end. This publication will not make the reader a world-recognized expert. However, the color technologist will find useful information within these pages. The information will improve his or her capabilities, as the knowledge of many technical experts are contained here. This book should be a resource center, or a starting point, for anyone beginning a coloring of plastics project where they are proceeding into unfamiliar territory. This book should also provide support to the accomplished colorist who desires to fill in that one area or areas where his or her background is not as strong or complete as it might be.

The creation of this publication started with the Color and Appearance Division (CAD) of the Society of Plastics Engineers. In 1979, a small volume was published titled *Coloring of Plastics*. This volume, with numerous authors, was edited by Thomas G. Webber under the sponsorship of the Color and Appearance Division. This was the first publication dedicated totally to the coloring of plastic materials. Thomas Webber's book was the first and only volume truly focusing on the subject. This book was the primer for the coloring of plastics industry. However, many years later the book was hopelessly outdated. The need for such a volume now is as great,

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if not greater, than ever. The CAD Board of Directors has promoted the preparation of a new, comprehensive, and up-to-date book for some time. The CAD Board of Directors approved the development of a new *Coloring of Plastics* book. This publication hopes to meet the challenge presented by the CAD Board of Directors. The board also selected the Chairman of its Education Committee Robert A. Charvat as editor. This started the long road of the development of a new *Coloring of Plastics* book under the sponsorship of the CAD.

The organization of the new book needed to include a number of issues and subjects not covered or not known at the time of the Webber book. The technology of colorants is light years ahead of where it was those many years ago. The ability to measure color and colored materials has made significant advances. The ability of computers to match colors accurately and quickly is standard procedure today but was very difficult, if not impossible, years ago. Our understanding of how we see color is significantly better now than years ago. The number of polymers available today is tremendously larger than at the time of the *Coloring of Plastics* book by Webber. The ability of new polymers to perform in demanding applications requires colorants also have the ability to meet these same demanding requirements. Keeping up with the introduction of these new polymers and their new applications is a problem not faced years ago.

All the above is prolog to this publication. This new publication is divided into two major parts. Volume I deals with the many technology issues that impact the coloring of plastics today. Volume II will cover the major polymer families and deliver *basic* information on the coloring of those polymers.

Volume I covers our understanding of color as a science. It provides the foundation for the many additional technological subjects. Measurement information along with matching, visually and instrumentally, will give the reader an understanding of the issues involved. Color specifications and a look at how statistical analysis can improve the consistency not only of colored polymer production runs but also of the colorants used to match the color are addressed. The basic families of colorants are explained to give the reader an understanding of the properties of these families. Basic information on the techniques usually employed to incorporate colorants into polymers as compounds or concentrates is discussed. Environmental issues as well as reuse of discarded materials are covered. An all-important issue, the potential interaction between colorants and other additives, is described to make the reader aware of potential problems with his or her projects. A diligent reader of Volume I will come away with an enhanced appreciation of the technology, issues, potential problems, and considerations a colorist must take into account if the coloring of a plastics project is to succeed.

Volume II will consider polymers, by giving an overview of the major polymer issues. The differences between a commodity and an engineering (exotic) polymer will be discussed. The impact of these differences will influence the reader when evaluating a strategy for the coloring of a plastic design. Volume II also describes the major polymer families. This description will cover such things as properties, advantages, disadvantages, and typical markets and applications for these polymer families. This followed by general requirements for colorants in these polymers. Basic information will be given on methods normally used to incorporate colorants into the polymers under discussion. Special issues concerning the coloring of polymers, including any particular problems or pitfalls that should be avoided, are described. This should give the reader or researcher vital information that will help to avoid major upsets in a coloring project. Each polymer chapter has a coloring matrix, which lists the more important colorant chemical family types and their expected performance in the polymer under discussion. This will supply information that will serve as a basic guideline to the reader, providing data that may help avoid a catastrophic failure involving the colorants used to color a specific polymer. This should be particularly useful in a coloring project using a polymer and/or colorant new to the reader. Basic attributes such as, but not limited to, colorant heat stability, physical properties, dispersability, and any special issues connected to the colorant/polymer combination are covered.

Finally, it is important to note that coatings and inks are polymers. The technical and process information contained here may also apply directly or indirectly to these polymeric materials. Therefore, this publication should have serious application capability to the coating, ink, and related industries.

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CHAPTER 2

Color as a Science

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2.1. INTRODUCTION

In our everyday life we are surrounded by the sights and sounds of our world. For the most part we take for granted the complexity of these sights and sounds and how our lives are impacted by our surroundings, that is, until we decide to take music lessons of some sort or we try to match the paint we bought three years ago to paint our family room. Then these complexities take on a new reality for us. For those of us in industry who have to deal with color problems every day, it is extremely frustrating how much the "science of coloring plastics" is trivialized. The result of this trivialization is often a crises situation where "color" was considered a nonissue until parts are rejected for color: "They don't look the same as they did in my office" or "All we did was change to a different polymer. That should not impact the color, should it?" or "You mean it makes a difference if I use the 2° observer instead of the 10° observer in my color difference calculations?" We could list hundreds of quotes to make our point, but it is not our intent to "preach" to the reader. We only wish to establish that the coloring of plastics is an elaborate, multivariable puzzle that requires a sound scientific approach and a clear understanding of all the components that make up this intricate world of color. It is the intent of this chapter to establish for the reader an accurate perception of the complexity of color science as well as a means to deal with this science in a logical manner. We will do this by helping the reader to gain a clear understanding of the variables associated with color science and how they interact. It is not the intent to re-create a text in detail

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of the science of color, for there are already several good books on the subject and we will reference these as we go along. Now, let us begin to explore this complex world of coloring plastic materials.

2.2. THE TRIAD

As we see color from strictly a physiological point of view we must consider a special "triad." This triad consists of a source of energy (the *light source*), an object that is illuminated by the energy (the *object*), and a detector (the *Observer*). The observer could be a human observer or alternatively a photosensitive detector attached to a computer. In the case of the human observer the eye is the detector, with the brain as the perceiver of the information sent to it from the eye. This combination of the eye and the brain creates the unique situation of *interpretation* of the physical information. This means that color exists in the mind of the viewer. This adds another dimension to color, the psychological dimension. We will cover this in more detail in another section. It is key to remember as we go through the discussion of the physical aspects of color that this human interpretative quality is, for us, the most important aspect. This triad is in a constant state of interaction. When it comes to the physical color stimulus, the three components of the triad do not act independent of each other. This means that as one progresses through this chapter, you keep in mind this constant interaction between the light source, the object, and the observer.

2.3. THE LIGHT SOURCE

Even though its the same color, it looks different. Why? Many conditions affect the way color appears. One of these is the light source. For instance, an apple may appear a bright delicious red under the sunlight at the farmer's market, but somehow does not look as good under the fluorescent lights at home. Except in rare situations, we do not see color without light. Furthermore, the light we see depends upon the characteristics of the light source under which an object is seen.

The light source is that which illuminates the object we are viewing. This light source emits energy in the electromagnetic spectrum. Light is the segment of electromagnetic radiation that also includes X rays, ultraviolet and infrared radiation, radio and TV waves, and cosmic radiation. The human eye can respond to electromagnetic radiation between 380 and 780 nm as light (colorimeter range is 400–700 nm). The part of this continuum that we are interested in is known as the visible spectrum. This is the portion of the electromagnetic to which our eyes respond. The visible spectrum, like all other portions of the entire spectrum, are divided into small segments that are described either by their frequency (cycles per second) or by the wavelength of one cycle. For the visible portion of the spectrum wavelength is most used. These wavelengths are expressed in units called nanometers ($1\,nm = 10^{-9}\,m$). Light with a short wavelength appears blue or violet. As the wavelength increases, the color appears to change through green, yellow, orange, and red. Radiation combining all the wavelengths of the visible spectrum in about equal amounts is

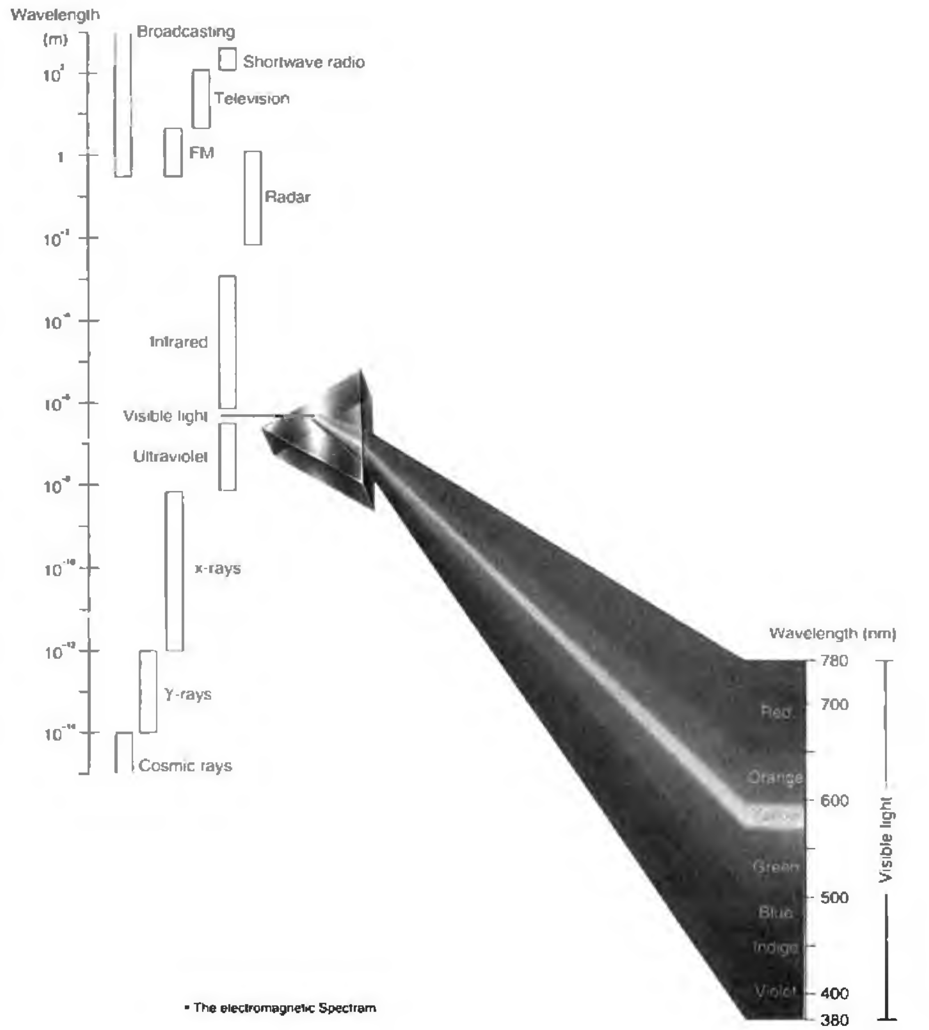

Figure 2.1. The electromagnetic spectrum and the portion that we see as visible light (Minolta, 1993).

perceived as white. This is best described with an illustration (see Fig. 2.1) (Minolta, 1993).

Radiant energy also affects the perception of color. More important to the perception of color than the radiant energy is the spectral distribution of the radiation from the light source. Everyone has experienced a colored object looking different in the sunlight, under cloudy skies, under fluorescent light, or under normal electric light bulbs. It is therefore essential to select a light source before defining color tolerances, whether these are for use in visual assessment or in colorimetry. Even northern light varies greatly depending on the time of day or season for reproducible result to be obtained, so as a general rule, an artificial light source is used.

Light sources can be described by their spectral power or energy distribution. This simply plots the amount of light (relative power) as a function of wavelength. Figures 2.1–2.5 are examples of standard light sources (Billmeyer and Saltzman, 1981).

For artificial light sources, two values are important: the color temperature in degrees Kelvin and the relative spectral distribution of the light source $S(\lambda)$, where λ shows that the radiant energy is dependent on wavelength.

2.3.1. Blackbodies

An important group of light sources are called *blackbodies*. We will not take the time here to discuss in detail the science of these sources, because they are well described in other texts (e.g., Billmeyer and Saltzman, 1981; Judd, 1964). The color temperature of a lamp is based on the radiation emitted by a blackbody. The important point to note here is that these sources are based on absolute temperature in degrees Kelvin (K = degrees Celsius + 273) of standard blackbodies such as tungsten-filaments. Thus, a 6500 K (D65) source is a blackbody heated to 6500 K. Figure 2.2 shows two such sources. The main principle to gain from this section on the light source is; each source has its own unique spectral power distribution and therefore will interact with the other two components of the triad according to this uniqueness. In other words, an object illuminated with a 6500 K source will appear different from the same object illuminated with a 2854 K source.

The total amount of energy from the source is also an important factor in the perception of color. If the energy is too low, we are not able to see the full color results. If the energy is too high, we are "blinded by the light." The ASTM standard D 1729–89 addresses the issue of level of illumination under section 5.1.2, Photometric Conditions; this is an excellent practice to adopt for color laboratories as it focuses on the visual evaluation of color in a controlled environment (ASTM D 1979–89).

The CIE (Commission Internationale de l'Eclairage) has selected a number of light sources from the wide range available with different spectral distribution and color temperature. The use of these standard illuminants is recommended and those used most commonly are listed here:

- Standard illuminant D65 (6500 K) represents average daylight.
- Standard illuminant A (2856 K) represents evening lighting in rooms (e.g., normal light bulb).
- Illuminant F2 (4230 K) refers to a cool white fluorescent (CWF) lamp.
- Illuminant F11 (4000 K) refers to a triple-band lamp (TL).

D65 is considered to be a better representation of natural daylight than illuminant C, which has a lower proportion of ultraviolet (UV) radiation than D65 (Huff, 1994).

Color assessment should be carried out using the illuminants specified and in a color assessment booth, such as is available from a number of manufacturers. The booth is usually equipped with at least three lamps to produce the various illuminants. A UV lamp is normally included as well. The inside of the color booth is painted neutral gray in order to prevent inaccuracies produced by reflection from the walls. *External light must be blocked out.*

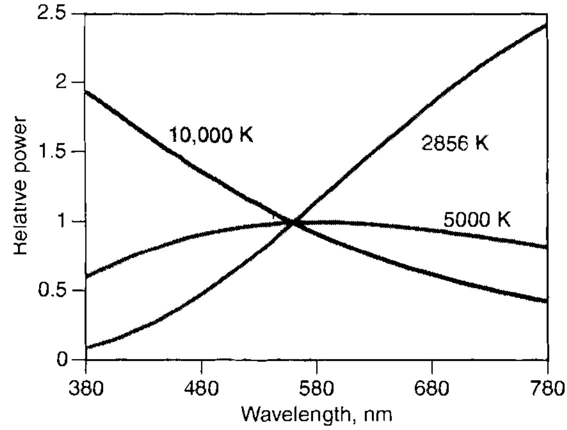

Figure 2.2. Spectral power distribution of blackbodies with color temperatures of 2854K (source A) and 6500K (Pivovonski, 1963; Billmeyer and Saltzman, 1981).

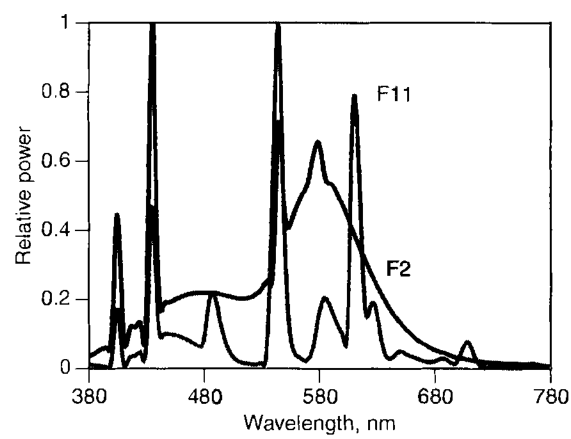

Figure 2.3. Spectral power distribution of cool white fluorescent lamp (IES, 1981; Billmeyer and Saltzman, 1981).

The objects that we often consider sources of light (the sun, light bulbs of many types, etc.) are seen by our eyes as white or almost white. Through a series of experiments using a prism, Newton discovered that this white light actually consists of all of the visible wavelengths described above (Newton, 1730). This is true when the source is said to be polychromatic, meaning it contains all wavelengths of light from 400 to 700nm. It is important to note that some sources that "appear" to be white may not contain all of the wavelengths of the visible spectrum. Some of the mixed halide lamps such as sodium and mercury are such sources. These present problems when viewing objects because they are not polychromatic. Later in the chapter we will discuss why this is true.