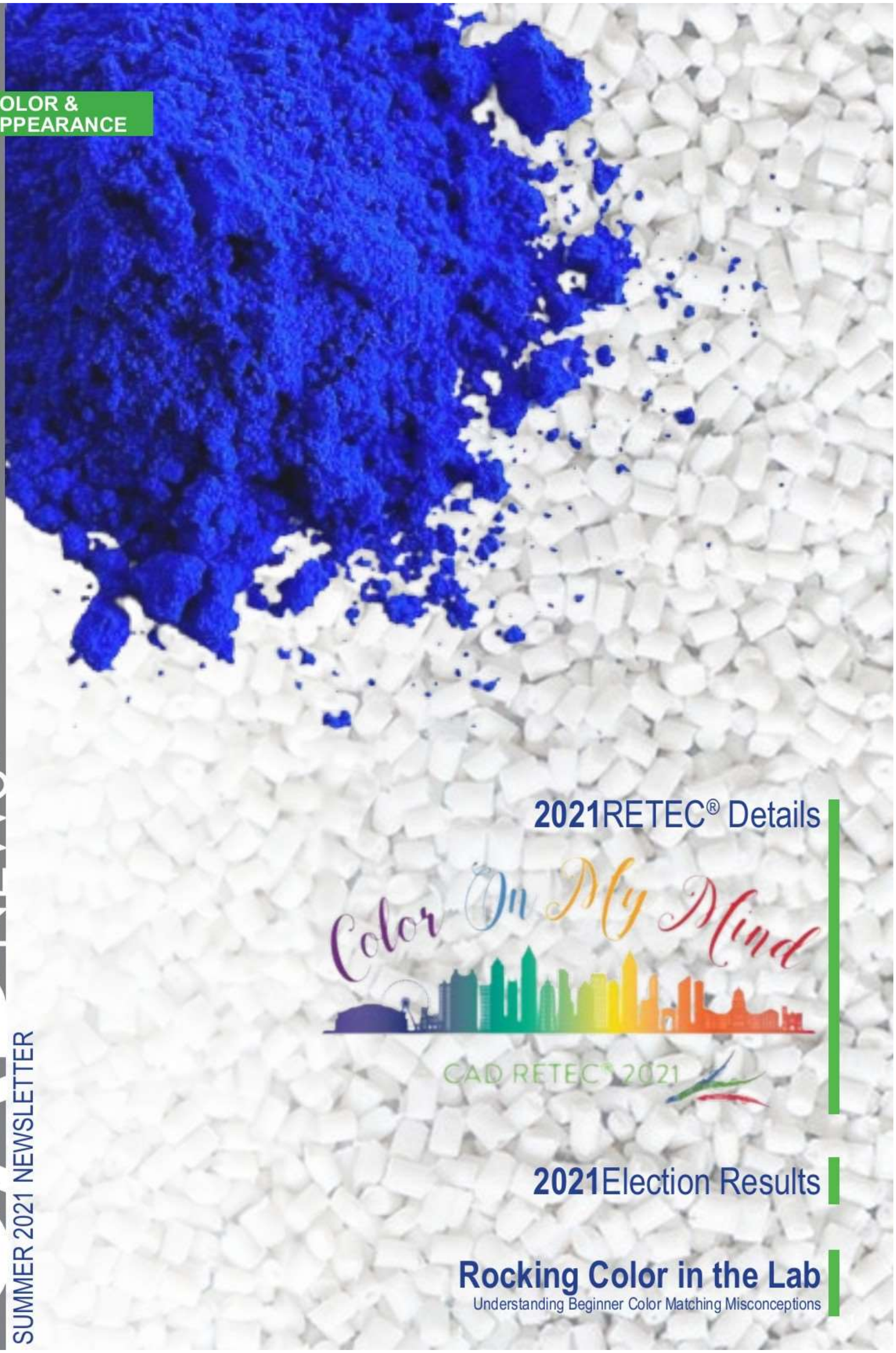
COLOR &
APPEARANCE

CAD NEWS®

SUMMER 2021 NEWSLETTER



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INVITATION TO ATTEND CAD BOARD MEETING

The Color and Appearance Division (CAD) holds 4 Board of Directors (BOD) meetings each year, either in person or virtually. Any CAD members in good standing with in SPE and has Color and Appearance as their selected division are welcomed to attend these meetings. If interested in attending these meetings, please contact the current CAD Chairperson or any BOD for more information.

CHAIRMAN'S MESSAGE

Dear SPE Colorant and Appearance Members,

Hello and Happy Summer! I hope everyone is doing well and this newsletter finds you with a smile on your face and a skip in your step. Unfortunately, we all have experienced loss of some type or another over the past 18 months and it is my hope that we can approach the future with a sense of healing and optimism as we continue to make progress in the fight against the pandemic.We are seeing some signs of normalcy, although the new normalcy may be somewhat different, and I cannot express how pleased I am that we are moving ahead with a live, yes, I said live, RETEC. The 59th annual RETEC conference, Color on My Mind, will be September 19-21st at the Atlanta Marriot Marquis. Betty Puckerin, RETEC Chair, and her team have been working diligently with the various committees to ensure another successful technical conference dedicated to the coloration of plastics.The daily grind of managing raw material shortages at near record high prices makes a live RETEC sound even more appealing. Good company, good conversation, a strong technical program, and some social activities are what you get with RETEC and it sure is something to look forward too! Visit www.specad.org for additional details and registration.

I would also like to take this opportunity to congratulate newly elected CAD BOD members. Seven incumbents and two new members were recently elected. The newly elected members are Brian Coleman and Josh Jacobs. Their three-year term begins July 1st. The executive committee succession is also effective July 1st and fellow board members elected George Lannuzzi as secretary. The CAD BOD leadership will be in good hands with Mark Tyler as Chairperson. Mark's positive energy combined with his knowledge and experience has fellow board members excited and looking forward to a promising year.Thank you all for the opportunity to serve as CAD BOD Chair. Having all meetings virtually, was far from a typical year; however, the resilience of the CAD BOD was on display once again and it was an honor to be a part of a great team effort. On behalf of the board, many thanks to all SPE CAD members, we could not do it with you and your support. See you in Atlanta!

Mark Freshwater
2020-2021 CAD BOD Chair

CONTRIBUTORS

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Mark Tyler

CADNEWS® Summer 2021Technical Content – Scott Heitzman

The Technical Content portion of our summer addition of CADNEWS® includes a best paper from 2019. Understanding Beginner Color Matching Misconceptions. The paper by Brian D Coleman of Celanese Corp. identifies a few common misconceptions; adding too much or too little or over-simplifying characterization of colorants. It is a great read or reread!

CADNEWS® Summer 2021 Color Notes – Scott Heitzman

Welcome to the second addition of CADNEWS® Color Notes. The idea is to create discussion and provide comments regarding questions you may have related to color and appearance, color measurements, and colorants in general. Do not miss your opportunity to anonymously ask our team of experts a question. Use this link to submit your questions. Our SPECAD Color Notes committee will provide a response to one or more of the submissions in the upcoming CADNEWS® letter.

Q – Are there test methods for heat buildup or total solar reflectance?

A – Our education committee reports: Yes, a good start is to review the ASTM methods listed below?

•ASTM D4803 – Standard test method for predicting Heat Buildup in PVC building products.
•ASTM D7990-15 – Standard test method using Reflectance Spectra to produce an Index of temperature rise in polymeric siding.
•ASTM E903 – Standard test method for Solar Absorbance, Reflectance, and Transmittance of materials using integrating spheres.
•ASTM C1549 – Standard test method for determination of Solar Reflectance Near Ambient Temperature using portable solar reflectometer.

We hope this gets you headed in the right direction and thanks for the question!

Milliken presents

Milliken: The Color Experts

Milliken & Company understands the power and value of color as it relates to branding. Humans are visual creatures, and color plays a key role in purchasing decisions, as it helps to inform, personalize and speak the brand language.

The company continues to tap into its vast experience in this space to develop solutions for a wide variety of end markets and end-use applications.

Milliken's color journey began in 1964, when it launched its proprietary Versatint® washable colorants for textile identification. In 1981, it introduced its Reactint® range of colorants for polyurethane (PU). Five years later, Milliken unveiled its ClearTint™ polymeric colorants for use in NX® UltraClear™ polypropylene (PP), which can be made only with its Millad® NX® 8000 clarifier.

The year 2019 marked a major step forward, with the introduction of both its KeyPlast® products, as well as its KeyPlast RESIST™ high-performance colorants for plastics.

Milliken technology helps to color a vast range of sectors, including agriculture and turf; automotive and transportation; building and construction; coatings, paints and inks; home and laundry care; and plastics.

Milliken's KeyPlast RESIST colorants address another key challenge — coloring high-performance engineering polymers with bright and vibrant hues. These colorant are used in the high demanding applications such as high voltage connectors, control systems, structural parts and metal replacement.

Using KeyPlast RESIST colorants compounders and resin producers, offer a vast spectrum of stable and reproducible colors suitable for use with a wide range of resins such as Polyamides, PPA's, Poly Sulphones and other high heat polymer blends and alloys.

Additionally, Milliken continues to keep its finger on the pulse of end-user and market trends, which it documents each year in its ColorDirection report that forecasts the key shades and hues for the coming year. In doing so, it offers a palette of carefully curated colors, while providing the stories behind the inspiration and motivation driving their popularity. Brand owners can leverage this expert information to help capture the mood of consumers through effective branding and personalization.

Milliken's diverse portfolio of colorants can enable product makers to realize their aims to deliver on those colors that will help drive and shape consumer preferences in the coming year.

From the R&D lab to the production floor, Milliken's Chemical Division stands ready to help customers leverage color to design new products, reinvigorate existing products, and create opportunities to grow in new markets and applications.

For more details and information please contact us or visit us online at ***chemical.milliken.com***

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COLOR &
APPEARANCE

ELECTION RESULTS

Election Results for Color and Appearance Board of Directors and Chapter Counsilor for term beginning July 1st, 2021 and ending June 30th 2024

Bruce Mulholland
Brian West
Earl Balthazar
Ed Ford
Josh Jacobs*
Jack Ladson
Kimberly Williamson
Cheryl Treat
Brian Coleman*

** Newly elected members to the BOD.*

Chapter Counsilor

Mercedes Landazuri

ANNUAL SPE CAD SURVEY RAFFLE

We are looking for gifts to use for the SPE CAD Survey Raffle that will be given away at the end of the conference proceedings. If you have a prize of $25 or more and want to supply for the raffle, please contact:

Chuck DePew or +1 765-914-3363

Mark Tyler
Color & Appearance Newsletter Editor

Editor's Note Summer 2021

Welcome to the Summer Newsletter and hope everyone in CAD is doing well. Summer is here and is heating up all over the country. Travel is picking up and the country is seeing places and businesses start to open up, and most excitingly, announcing RETEC® 2021 is Live!

This edition of the CADNEWS® will highlight on the events and preliminary Technical Program for the upcoming RETEC® 2021 in Atlanta GA. You can see what events are scheduled and times, registration times for this year as well as information on the Preliminary Technical Program. Registration for the event as well as the hotel and more detailed information can be found on the CAD Website RETEC® 2021 landing page (Click Here) We look forward to getting everyone back together and having a great RETEC.

Since our last issue in the Spring, we held our annual elections for the Board of Directors where the membership elected 2 new members to the BOD and retained 7 incumbents. You can see the results in this issue and well as re-electing our chapter Councilor, Mercedes Landazuri. We welcome and congratulate you all.

Last but not least, the CAD Division, would like to thank Mark Freshwater for his work and dedication as his term of Division Chairperson comes to a close July 1st. Mark did a fantastic job and would not like to be the person who has to follow Mark as Chair.

Hope you enjoy this edition of the CADNEWS® and truly hope you all can make it to Atlanta in September.

CAD RETEC®
Atlanta, Georgia • September 19-22, 2021
Presented by SPE Color and Appearance Division

Pre-registration online Go to [2021 CAD RETEC HOME]

Onsite Registration

- Sunday 19 September 1:00 PM – 7:00 PM
- Monday 20 September 7:30 AM – 5:00 PM
- Tuesday 21 September 7:30 AM – 3:00 PM

Preconference Tutorial *Coloring of Plastics*

Presented by Bruce Mulholland, SPE Fellow
Sunday 19th September 8:00 AM – 4:30 PM

Fee: $525 (Must Pre-register for event. Extra fee not included with CAD RETEC® 2021 registration)

CAD RETEC® 2021 Golf Outing

Sunday September 19th, 2021
Bears Best Atlanta
Registration 8:30 to 10:00 AM
Shotgun start at 10:00 AM

Price: $ 110.00 per golfer
Includes: the range, green fees, cart fee, lunch, Awards (hole prizes), scramble format

For more details, visit the www.specad.org

CAD RETEC® 2021 Fun Run

Tuesday 21 September 20201
Sponsored by *DLC*

$25 Registration fee
All proceeds go to Habitat for Humanity
SPE CAD will match every $25 donation

CAD RETEC®
Atlanta, Georgia • September 19-22, 2021
Presented by SPE Color and Appearance Division

(SELECT ONLY ONE TYPE OF REGISTRATION)

SPE Member	**2021**
❑ Advance	$410
❑ Late / Onsite (After 8/20/21)	$510

SPE Non-Member:

❑ Advance	$630
❑ Late/Onsite (After 8/20/21)	$730

OTHER Registration Types:

❑ Speakers/Moderator	$190
❑ Student (w/ Valid Student ID):	$ 50
❑ Emeritus:	$100
❑ Tabletop advanced registration	$1,350
❑ Tabletop late reg (After 8/20/21)	$1,550

EXTRA CONFERENCE LITERATURE:

❑ Extra RETEC 2021 $115 x ___ = $_____
❑ Archive DVD (1961-2007) $175 x ___ = $_____
(available on site)

OTHER EVENTS REGISTRATION/RSVP

❑ Golf Outing (Sunday):	$ 105
❑	
❑ 5K Fun Walk (Tuesday):	$ 25
❑	
❑ "Coloring of Plastics" Tutorial (Sunday):	$525

CLICK HERE TO REGISTER ONLINE!

spe CAD RETEC®
Atlanta, Georgia • September 19-22, 2021
Presented by SPE Color and Appearance Division

Color On My Mind
CAD RETEC® 2021

Preliminary Technical Program
Monday 20 September 2021

Time	Category	Speaker/Company	Title/Sponsor
7:30-8:30 AM	**Breakfast**		**Sponsored by DCL**
8:45 AM	Opening Remarks	Betty Puckerin - Ampacet	Welcome to CAD RETEC® 2021 in Atlanta, GA
9:00 AM	Keynote	Doreen Becker / Ampacet	Sustainability for Colors 2.0
9:30 AM	Paper	Derek Schaefer / UBQ Materials	From Trash to Gold: How a New Bio-Plastic Is Paving the Way for a More Sustainable Economy
10:00 AM	**Break**	**Exhibits open (Exhibitors) Exhibit Hall**	**Sponsored by TBD**
10:30 AM	Paper	Frank Neuber / Clariant	Fully Sustainable Micronized Waxes to Improve Dispersion in Engineering Polymers
11:00 AM	Paper	Alex Capuz / Ferro	Leveraging Pigments' NIR Reflecting Properties to Overcome the Challenge of Sorting Recyclable Black Plastics
11:30 AM	Paper	Eric Andrews / Colour Synthesis Solutions	AP(2020): Evaluating the Influence of Colourants on Plastic Additives & Degradation Process in Food-Contact PET
12:00-1:30 PM	**Lunch**		**Sponsored By TBD**
1:30 PM	Keynote	Andy Francis - Q-Lab	UVC Durability Testing of Plastics
2:00 PM	Panel Discussion	Tony Tanner - Moderator	COVID-19 and it's Impact on
3:00 PM	**Break**	**Exhibit Area Exhibit Hall**	**Sponsored By TBD**
3:30 PM	Paper	Chuck Hoover / Cathay	Iron Oxide Pigment Processing and its Impact on the Resulting Color in Plastics
4:00 PM	Paper	Bonnie Piro / Sudarshan	Mica: Technology Impacts on Color Design for Plastics
4:45 PM	**NTF**	**Scott Heitzman - Moderator**	**New Technology Forum**

Network Reception
Monday 21 September 2021
Exhibitor Area, 6:00 pm – 7 pm
Sponsored by ***The Shepherd Color Company***

CAD RETEC®
Atlanta, Georgia • September 19-22, 2021
Presented by SPE Color and Appearance Division

Color On My Mind
CAD RETEC® 2021

Preliminary Technical Program

Tuesday 21 September 2021

Time	Category	Speaker/Company	Title/Sponsor
7:00 AM	**Activity**	**Fun Run/Walk** **Marriott Marquis Lobby**	**Sponsored by DCL**
8:50 AM	Opening Remarks	Betty Puckerin - Ampacet	*Welcome to Day 2 CAD RETEC® 2021 in Atlanta, GA*
9:00 AM	Paper	Andrew Yankosky / Sun Chemical	Pigment Lightfastness - A Comparison of Fluorescent Bulb (Fluorescent Deluxe Daylight) and Light Emitting Diode Array (LED) Exposure
9:30 AM	Paper	Brent Johnson / Milliken	Understanding and Improving Color QC
10:00 AM	**Break**	**Exhibit Area** **Exhibit Hall**	**Sponsored by TBD**
10:30 AM	Paper	Fang Wang / Colors & Effects	Pigment Dispersion Quality Assessment and Application Suitability Analysis
11:00 AM	Paper	Joseph Fay / BASF	Maintaining Outdoor Plastics Appearance: HALS, UVA's or Both? Or Nothing?
11:30 AM	Paper	Thomas R. Maier / Monolith	The New Plasma Black: Performance and Environmental Benefit
12:00 PM	**Luncheon**	**Awards Luncheon** **Exhibit Hall**	**Sponsored by Tronox**
1:30 PM	Paper	Kevin Lucero / EMD Group	High Quality Specialty Effect Pigments for Plastic Applications
2:00 PM	Paper	Tom Vetterly / Interspersal	Concerning the Environmental Health and Safety of Hindered Amine Light Stabilizers based upon piperidinyl esters.
2:30 PM	**Break**	**Exhibit Area** **Exhibit Hall**	**Sponsored by TBD**
3:00 PM	Paper	Mike Willis - Sun Chemical	Color Science from SPECAD
3:30 PM	Keynote	Mark Ryan / Shepherd Color	3D Printing Filaments: Effect of Pigmentation on Printing and Final Properties
4:00 PM	Closing Remarks	Betty Puckerin - Ampacet	Raffle (Prizes TBD) ***Must be present to win!!***
5:00 PM			**Conference Ends**

SOCIETY OF PLASTICS ENGINEERS

2021 CAD RETEC® GOLF OUTING

SUNDAY 09.19.2021

Bear's Best
Atlanta

BEAR'S BEST ATLANTA
5342 Aldeburgh Drive | Suwanee, GA 30024
(678) 714-2582

Registration and Lunch:	9:00 am - 10:00 am
Shotgun Start:	10:00 am

Conference Opening Ceremony starts at 8:00pm

Price: $110.00
Includes Range, Golf and Cart Fees, Lunch

Awards (Hole Prizes)
Scramble Format
Teams will be drawn based on handicaps this year.

When registering, after your name input your typical 18 hole or 9 hole score. Please be honest to make this fair

FOR QUESTIONS, PLEASE CONTACT:
MARK TYLER (570) 952.5255
MARK FRESHWATER (201) 665.0091
ALEX PROSAPIO (845) 641.0596

Bear’s Best Atlanta is ranked in the top ten courses you can play in America by Golf Magazine. Located in the upscale gated community of Edinburgh, Bear’s Best is a high-end daily fee course focused on corporate entertaining, golf outings and providing the experience of an luxurious private club at a public facility.

Jack Nicklaus selected 18 holes from his more than 300 course designs worldwide and put them into one extraordinary round of golf at Bear’s Best Atlanta. Among the courses featured are Castle Pines, Muirfield Village, PGA National Championship Course, Sherwood Country Club, Shoal Creek and Gleneagles.

ROCKING COLOR IN THE LAB: UNDERSTANDING BEGINNER COLOR MATCHING MISCONCEPTIONS

Brian D. Coleman
Celanese Corporation
Florence, KY 41042

Abstract

This paper seeks to supplant some of the trial-and-error learning by those new to color matching by identifying and explaining a few common beginner misconceptions. Color formulation scenarios addressed include: adding too much pigment, adding too little pigment, adding just black to fix lightness, overlooking the use of CIE C* and h when correcting color and oversimplifying the characterization of colorants. The consequences and underlying concepts of each scenario are presented along with alternative best practices.

Introduction

Consistently successful and efficient color matching in plastics requires a solid foundation in color theory, appropriate use of color hardware and software and the application of insights learned through experience and training. Individuals new to color matching obviously do not have the benefit of experience and do not always have access to a mentor so often lessons are learned through trial and error. This paper is a collection of lessons that I have learned over my career in coloring plastics. Many of the lessons were via trial and error, some resulting in off-spec material that is probably still in a warehouse somewhere waiting to be worked off! It is my intention that this paper serve as a supplement to the usual training of individuals new to working with color in plastics, specifically color matchers. A basic understanding of CIELab color coordinates, color difference and spectral curves is assumed throughout.

White and black pigments could be considered special cases in that they do not have selective absorption: regions of absorption and other regions of reflection. White colorants strongly reflect all wavelengths of light and therefore do not strongly absorb any color. Black colorants are just the opposite: they strongly absorb all wavelengths of visible light and do not strongly reflect any color. Graphically these appear as more or less horizontal spectral curves in the visible region; white near the top and black near the bottom of the spectrograph (Figure 4). So what happens when a black is added to an existing color? Just like any other colorant, it subtracts light from the regions in which it absorbs light, which in the case of black is all regions! For example, in a brown custom color, the addition of black detracts from reflectance in all portions of the spectrum. Graphically, the addition of black lowers the reflectance curve across the entire spectrum (Figure 5). This decrease is not equal in all regions, the higher reflectance areas are more impacted than the lower reflectance areas. So rather than imparting a uniform drop in reflectance, the black changes the overall shape of the curve and thereby changes the chroma and hue of the color in addition to the lightness.

The better strategy for moving a spectral curve up or down on the spectrograph is through adjusting the ratio of non-white colorants to white. To darken a brown color without affecting the overall shape the curve, one would add an equal percentage of all the non-white colorants in the formula. For instance, the movement from light to dark brown shown in Figure 6 required a 40% increase in the yellow, red and black components of the light brown. Doing so imparted a spectral curve shift down but not a change in the overall shape as was seen when adding just black.

Using only Da* and Db* for adjustments

New color matchers are introduced to the CIELab color space model early in their training. After all, that system is how most of the plastics industry quantitatively describe color. Color matches are approved by L*, a* and b* values and material lots are released based on those same values. The opponent coordinates (-L* and +L*, -a* and +a*, -b* and +b*) are easy to understand and apply. If a batch has a positive Da*, it is too red; a negative Da*, it is too green. New color matchers are often eager to embrace the L*a*b* system as it affords support for their color assessments and sometimes replaces their subjective assessments altogether! Who doesn't like some data to point to as justification for their decisions? Whatever the motivation, many new to color assessment are well versed in describing a color in terms of L*, a* and b*.

Though the L*a*b* coordinates lend themselves well to communicating color difference in layperson terms – too light, too blue, too yellow, etc. – they can be misleading to the individual seeking to correct a color. Because of the opponent nature of the coordinates, it can be easy to make mistakes based on them. For instance, what if one were faced with the bright yellow batch whose Db* was positive versus the standard. The positive Db* would be correctly interpreted as the batch being too yellow compared to the standard. If the batch is too yellow and the opposite of yellow in the CIELab system is blue, wouldn't the addition of a blue colorant be logical? Similarly, if a green custom shade batch had a negative Da* (too green) versus its standard, wouldn't the addition of a red colorant be warranted? Adding opponent colorants in these cases would prove detrimental, at best using a relatively expensive ingredient to dull down a color and at worst entirely changing the shade of the color! It is proposed that a more effective way to consider color difference is in terms of chroma and hue rather than a* and b*.

Chroma and hue are simply a different approach to describing a color or color difference. *Chroma* refers to the brightness or saturation of a color. In a*b* 2-dimensional color space, chroma is how far away a color is from the white/gray/black origin. The farther away from the achromatic center, the higher the chroma of a color (Figure 7). A chroma value describes the distance from that achromatic center, which has 0 chroma. If one were to compare fire engine red to brick red, the fire engine red may have a chroma value of 60 while brick red may be at only 20.

Hue refers to the shade of a colored object. Hue is what is distinguished when people add modifiers to different shades of the same basic color. For instance, lemon yellow and school bus yellow are both yellows but the words conjure very different shades: one a greenish yellow, the other a reddish yellow. In a*b* 2-dimensional color space, different hues are described by the angles relative to the positive a* axis moving counter-clockwise. Colors that fall directly on the positive a* axis would have a hue angle of 0°. Those on the positive b* axis would have a hue angle of 90°, the negative a* axis would have a hue angle of 180° and so forth. These individual angles offer a quantitative alternative to the verbal descriptors. So perhaps a lemon yellow would have a hue angle of 100° and school bus yellow would have a hue angle of 75°.

Chroma and hue values are derived from CIE's a* and b* values. In CIE, chroma is abbreviated by C* and hue is represented by h; the difference values are simply DC* and DH*. It is important to understand that C* and h are very closely related to a* and b*, indeed they are just a different way to describe the same point in color space. In 3-dimensional color space the L* value is the same when using both a*,b* and C*h. So, a single color can be described by L, *a* and b* values or by L*, C* and h values. Consider the color represented by point A in Figure 8. In a*b* space, it would be described as a* = 3 and b* = 4. That same point in the same plane could also be described as C* = 5 and h = 53.1°.

The value of knowing chroma and hue or color difference based on DC* and DH* is the direct relationship with how to adjust the color. Back to the example of a yellow batch that is too yellow. Rather than looking at the Db* value and thinking of the batch as too yellow and prompting one to think of adding blue, it is better to consider the batch too chromatic. Instead of thinking of the opposite color, one should be thinking about how to lower the chroma. In the case of the yellow, adding a blue would not just lower the chroma but would also shift the hue dramatically toward green. Thinking about the move in terms of lowering the chroma, one could add a dull yellow to the batch, thereby decreasing the chroma while maintaining the hue. So the proper correction may be adding a lower chroma yellow colorant and not considering a blue pigment at all! A very effective way to lower the chroma of opaque earth tones from anywhere in color space is to add a combination of white and black. By adding white and/or black, one is essentially adding the components of the achromatic center and thereby moving the color toward that center or lower in chroma. If one were to add blue to a yellowish brown, the hue of the color would move toward green! In contrast, by adding white and/or black, the color just loses chroma and does not shift as dramatically green. In both cases, if in the formulating stage, one could simply remove some of the chromatic colorants rather than adding anything.

Adding too much pigment

Strategies for lowering chroma include removing the chromatic colorants, adding colorants that are duller than the custom shade but near the hue angle and adding a combination of white and black. But what do you do when the chroma is too low? If in the formulation stage, one could always remove some of the lower chroma colorants like black. If adjusting a production batch where re-formulation is not an option, why not just add the chromatic colorants? That is likely the only option to try to brighten the color but it is not guaranteed to work.

Understanding color build of pigments and dyes can help guide their addition. *Color build* refers to the changes in color with changes in colorant concentration. The chroma vs. hue plot of an organic red pigment in polyamide is an example of one way to characterize color build (Figure 9). One cannot add a chromatic colorant without affecting the hue. In other words, adding a bright pigment or dye does not increase the chroma alone, the hue will also change. But why does the hue change when you're just adding more of the same colorant? If I go from a 50 g add to a 500 g add of the same pigment, shouldn't the color just get brighter? Two observations are presented explaining why adding more pigment doesn't solely increase the brightness.

One conclusion drawn from a color build curve is that colorants change hue as their concentration builds. Notice in Figure 9 how the hue of the organic red pigment moves dramatically as its concentration increases. As more pigment is added, the shade moves more yellow, from 0.03% to 1.0%. This case is considering the color of one pigment alone but one should expect the same behavior when the pigment is used in combination with other colorants. It is clear that the addition of a colorant will not just increase the chroma but will alter the hue as well. In short, concentration is not a simple lever for chroma; other attributes of the color are also changed.

Figure 9 serves to illustrate an important concept: colorants, especially organic pigments, reach a point of maximum chroma relative to concentration. Beyond the point of maximum chroma, the chroma will no longer increase regardless of how much pigment is added. So why is it important to be aware of this concept?

First, consider how the color is changing with addition of a pigment beyond its maximum chroma point. The color is changing hue and losing chroma as shown by the points at 0.5% and 1.0% in Figure 9. There is usually a more efficient way of shifting the hue and lowering the chroma versus adding a chromatic pigment beyond its maximum chroma point. In Figure 9, one could move from the aforementioned points by adding a dull, yellow shade red like iron oxide, Pigment Red (PR) 101. Not only is this addition more cost effective (organic pigments can be several times the cost of PR 101) but it limits the concentration of the organic pigment. Polymers have a limit of how much pigment or dye can be successfully incorporated. Too much pigment can degrade mechanical properties of the finished article and can make extrusion challenging especially if strand integrity is required. Furthermore, if too much pigment is used it could overload the system leaving a certain fraction of the pigment crystals residing on the surface of the pellets or the finished article. Crystals residing on the surface can easily be rubbed off (color transfer) which is almost always undesirable! Similarly when coloring with dyes, the solubility limit of the polymer can be exceeded if too much dye is added. As before, the dye crystals can then reside on the surface and be prone to rub-off.

So, indiscriminately adding more and more colorants to a formula can result in expensive, diminishing returns if the maximum chroma level is surpassed. It can also result in an over-loading of the polymer system. Overloaded systems can yield mechanical issues, processing issues and the deposition of colored crystals on the surface of pellets or finished articles. So, incorporating too much colorant can be a bad thing, what about adding too little?

Adding too little pigment

A good color match is more than just matching a color with a lab trial. Additionally a good match is one whose formula is robust enough to yield consistently acceptable color after scale up. Adding too little colorant can affect consistency both in a physical sense and sometimes in a chemical sense.

In making any physical blend of solids, the chief objective is achieving homogeneity: consistency throughout the entire volume of the blend. The first quarter of the blend should be identical to all other quarters. Homogeneity becomes exceedingly challenging when an ingredient is present in a very small quantity and even more so when the ingredient has a high density. How can one be sure that 10 mg of pigment or dye is equally distributed over a 1 kg batch? One mitigating strategy is to employ vigorous blending. Mixing in a high intensity mixer or with a paint shaker will yield better homogeneity than just manually shaking the batch in a bag. Sometimes powder resins are used in part or in full to create a blend that is less prone to settling out (colorant powders separating from resin pellets). Often ingredients added in very small quantities will be delivered in a dilution. Pigments or dyes can be diluted with ingredients already in the formula including lubricants, dispersants, waxes or the resin itself. Of course, the homogeneity of the dilution is paramount to its successful use. If homogenous, using a dilution improves the reliability of weigh up by increasing the mass several fold resulting in weighing to more significant figures and measuring in a region significantly beyond the sensitivity of the balance or scale. For instance, instead of weighing 5 mg of a 100% active dye, one would weigh 500 mg of a 1% active dilution. On an analytical balance sensitive to 1 mg, the dilution mass is 500 times the sensitivity as opposed to just 5 times[1] using the 100% active dye.

Beyond the physical mixing, some pigments behave differently at very low concentrations and therefore should be used carefully. Pigments by definition remain insoluble, discrete particles within their system. Low levels of organic pigments have the tendency to dissolve in the polymer. When the particles of the pigments have dissolved, the colorant essentially exists as a dye. The transition from insoluble to soluble is usually accompanied by shifts in hue and chroma. This color change is inconsistent with the color build of the pigment. Consider the same organic red now in Figure 10. Notice how the hue shifts back toward yellow at 0.01% instead of continuing to move blue with decreasing concentration as the color build would seem to predict.[2] It can be concluded from the color build plot that at some concentration between 0.03% and 0.01%, the pigment has dissolved. The exact point of dissolution is variable depending on the heat and shear experienced by the system which makes the color shift difficult to predict. Moreover, if color formulating software is employed, it will not be able to predict such a shift as the colorants are not usually characterized at low enough levels to capture this behavior. Consider the case of using this organic red in a lab setting at 0.03%. It behaves predictably as a pigment on the lab equipment but what happens when the formula is run in a production setting? Will the extra shear render the pigment soluble thereby shifting the final color out of tolerance. It's difficult to determine so it's best to ensure that very low levels of organic pigments are avoided.

Oversimplifying the characterization of colorants

One of the most difficult aspects of color matching is the selection of pigments and dyes suitable for the polymer, the process and the application. Hopefully someone new to color matching will have a trusted advisor or thorough notes to rely upon but even then we tend to categorize colorants into groups based on various criteria. For instance, one may mentally group together all colorants with indirect food contact clearance with the U.S. Food and Drug Administration (FDA). Similarly,

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1 A quick search of online publications yielded varying suggestions for minimum quantities ranging from 20 to 900 times the readability of the balance.

2 In addition to color change in the visible spectrum, polycyclic organic pigments like quinacridones and perylenes, when dissolved will often fluoresce when exposed to UV light.

other groupings may be based on heat stability or ultra violet (UV) resistance. With the myriad of colorants commercially available to a color matcher, the tactic of grouping is understandable; it breaks down a large population into manageable chunks. However, these categories are most times oversimplified into a positive list: inclusion on the list means the criterion has been met. It is a "yes" or "no" system with no room for a "maybe" or "sometimes"!

Food contact clearance

Consider the seemingly basic case of FDA indirect food contact clearance. Everyone has an FDA list of some sort but unless it details the specific qualifiers – polymer, concentration and temperature conditions of use – it can be misleading. What if one needs a mid-shade yellow dye for polystyrene that must be FDA? My FDA list shows that my workhorse yellow dye for polyester, Pigment Yellow (PY) 147, is FDA so what's the problem? The exact wording form 21 CFR 178.3297 regarding PY 147 follows:

For use at levels not to exceed 0.25 percent by weight of polyethylene phthalate polymers that comply with 177.1630 of this chapter.

Immediately evident is the limitation of polymer systems to only polyesters. Use of that colorant in polystyrene is *not* cleared for food contact. Notice also that there is a limit to how concentrated PY 147 can be in a polyester and still be food contact cleared. Any level exceeding 0.25% by weight is *not* approved for food contact so even in the appropriate polymer, one cannot add endlessly. Even if the previous polymer and concentration restrictions are met, the article may still not be FDA cleared based on its use. The balance of the verbiage from 21 CFR 178.3297 regarding PY 147 follows

The finished articles are to contact food only under conditions of use E, F, and G described in … 176.170(c) of this chapter, except, when such articles are used with food types III, IV-A, and V, described in … 176.170(c) of this chapter, the finished articles are to contact food only under conditions of use D, E, F, and G.

So the FDA clearance is further restricted to only specific temperature conditions of use (E – G or D – G) and those are based on the type of food that will contact the article! The temperature conditions of use and food types tables are reproduced herein as Table 3 and Table 4 respectively. There are colorants like PB 15:x, PG 7 and PV 19 whose clearances have no limitation on polymer type, concentration[3], conditions of use or food type. But clearly, in the case of PY 147 FDA clearance is not nearly as simple as it is or it is not. There are many more FDA cleared colorants for which there are specific restrictions than those with no limits, hence it is important to always consider the details rather than rely on a simple binary classification.

Heat stability

Colorants are also sometimes categorized by their heat stability: they are heat stable or they are not. Unfortunately, like with FDA clearance, the details prove this grouping is too broad and can be misleading.

Heat stability characterizations, especially for organic colorants, at a minimum should carry at least two qualifiers: polymer and concentration. Pigments that are rock solid in a one polymer system may be completely useless in another due to insufficient heat stability (Table 5). Workhorse yellow pigments like PY 180 and PY 191 can be stable up to 300°C in polyolefins yet are generally considered unsuitable at any temperature in polyamides or polyesters. Should someone consider either one of those yellows heat stable? Yes but only in specific polymers.

Perhaps easier to overlook is how a pigment's heat stability changes with concentration. Significant changes due to concentration are most likely in organic pigments that are prone to solubility. Not all organic pigments behave the same; consider the juxtaposition of a phthalo blue (PB 15:3) with a mono-azo red (PR 53:1) in Figure 11. Both pigments are considered heat stable enough for polyolefins but they differ greatly based on concentration. At concentrations above 0.1% both pigments are very well suited for most polyolefin processing. Phthalo blue is very robust: maintaining heat stability at 300 °C over all of its concentrations. The mono-azo red begins to faulter at levels less than 0.1%. Indeed PR 53:1 levels approaching 0.03% and lower should only be considered for the lowest temperature polyolefins if any at all! In general, the smaller, asymmetrical organic pigments are more prone to this concentration effect on heat stability than their larger, symmetrical counterparts.

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3 While there is no specific concentration limit called out in the notes for these colorant chemistries, all colorants listed in 21 CFR 178.3297 are subject to paragraph (b) which in part states that a colorant should be used at levels "which are not in excess of those reasonably required to accomplish the intended coloring effect"

UV stability
Finally, formulators tend to also broadly group colorants as UV stable or not. Again, this binary choice can be too limited to be reliable.

First what is meant by UV stable? Does it refer to fastness to light or fastness to weather or both? With organic pigments and dyes the difference between lightfastness and weatherfastness can be dramatic so distinguishing the two is very important. *Lightfastness* refers to the ability of colorant to withstand radiation from a light source, usually the sun, in an indoor environment. In contrast, *weatherfastness* is the ability of a colorant to withstand sunlight and other outdoor conditions like rain, condensation, evaporation and environmental chemicals. The primary difference between the two is water. The presence of water generally accelerates the photo-oxidation of the system and thus is more degradative than just light.

While searching for a weatherable bright orange pigment for polyolefin playground equipment one may consider Pigment Orange (PO) 64. Referring to a manufacturer's literature, PO 64 is bright and has a lightfastness rating at 0.1% of 7 - 8 out of a perfect rating of 8. A 7 - 8 rating out of 8 possible sounds good so would this work in the playground part? No, because the weatherfastness at 0.1% is only a 3 out of a perfect 5; that is significant color change! The playground equipment exposure is best modeled by weathering tests (radiation and water) not lightfastness tests (just radiation). Conflating lightfastness and weatherfastness can lead to severe and costly color failures.

So, if the descriptors *UV stable* or *UV resistant* are too broad, what if we use the terms *lightfast* and *weatherfast*? Even when distinguished properly, often a single determination (weatherfast or not) cannot be made. The presence of titanium dioxide (TiO_2) white almost always negatively impacts the light and weatherfastness of colorant, especially organic pigments and dyes. Titanium dioxide may be acting in at least three ways to degrade weathering performance. First, it very efficiently scatters light that strikes the object. High scattering necessarily results in a longer path for the light within the object and consequently more probability to interact with a colorant. In contrast, a colored object with no TiO_2 will allow some light to pass through it. Second, the scattering imparted by TiO_2 leaves only the very surface of the part to be visible by an observer. Again, consider a color created without TiO_2. The observer perceives color from the surface of the part and from the bulk of the part (below the surface). The white pigment limits the quantity of colored pigment creating the color to a thin layer: a fraction of all of the pigment or dye. Last, it is well documented that untreated TiO_2 can oxidize and release radicals that accelerate system degradation.

Pigment Orange 61 is a high performance organic pigment which one may be inclined to consider a weatherfast pigment. Indeed looking at a supplier's gray scale rating for 0.05% and 0.1% mass tones (colored pigment only, no white), it appears to be very weatherable with 4 and 4 – 5 ratings (out of a possible 5) respectively. But these same levels combined with 1.0% TiO_2 yield gray scale results of <3! So is it wise to classify PO 61 as a weatherfast pigment? It's probably best to think of it as potentially suitable for outdoor applications depending on the level of TiO_2 needed in the custom shade.

Conclusion

Adjusting and formulating colors in plastics can be a daunting undertaking for someone new to the craft. After all, the terminology, theory and methods are taught in almost no schools. No amount of schooling or training will ever replace the lessons learned on the job. Folks new to color would be well served to take away a few key points from this paper. Color is not easy; use all of the tools available to you, like spectral curves and C* and h. Color is rarely as simple as it seems at first, like adding just black to darken a color or that adding more pigment or dye will just make the color brighter. Be careful with broad characterizations of colorants; the details should not be forgotten. Hopefully armed with the information presented herein, the new colorist will travel the rocky road to proficiency a little more easily.

Acknowledgements

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References

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Berns, R. (2000). *Billmeyer and Saltzman's Principles of Color Technology*, New York: John Wiley & Sons Inc.

Table 1. CIELab values of a brown before and after the addition of a black pigment; D65 illuminant, 10° observer

Sample	L*	a*	b*	C*	h
Brown	54.19	14.31	15.64	21.20	47.55
Brown + black	52.81	9.10	13.27	16.09	55.55

Table 2. Conditions of use adapted from 21CFR Section 176.170(c), Table 2

Condition of Use	
A	High temperature heat sterilized (e.g., over 212 °F)
B	Boiling water sterilized
C	Hot filled or pasteurized above 150 °F
D	Hot filled or pasteurized below 150 °F
E	Room temperature filled and stored (no thermal treatment in the container)
F	Refrigerated storage (no thermal treatment in the container)
G	Frozen storage (no thermal treatment in the container)
H	Frozen or refrigerated storage: Ready-prepared foods intended to be reheated in container at time of use

Table 3. Food types adapted from 21CFR Section 176.170(c), Table 1

Types of Raw and Processed Foods		
I	Nonacid, aqueous products; may contain salt or sugar or both (pH about 5.0)	
II	Acid, aqueous products; may contain salt or sugar or both, and including oil-in-water emulsions of low- or high-fat content	
III	Aqueous, acid or nonacid products containing free oil or fat; may contain salt, and including water-in-oil emulsions of low- or high-fat content	
IV	Dairy products and modifications	
		A. Water-in-oil emulsions, high- or low-fat
		B. Oil-in-water emulsions, high- or low-fat
V	Low-moisture fats and oils	
VI	Beverages	
		A. Containing up to 8 percent alcohol
		B. Nonalcoholic
		C. Containing more than 8 percent alcohol
VII	Bakery products other than those included under Types VIII or IX of this table:	
		A. Moist bakery products with surface containing free fat or oil
		B. Moist bakery products with surface containing no free fat or oil
VIII	Dry solids with the surface containing no free fat or oil (no end test required)	
IX	Dry solids with the surface containing free fat or oil	

Table 4. General recommendations for heat stability of selected organic pigments

	Heat stability suitable for:		
Colour Index name	Polyolefins	Polyamide	Polyester
Pigment Yellow 110	Yes	No	No
Pigment Yellow 191	Yes	No	No
Pigment Red 254	Yes	No	No
Pigment Red 170	Yes	No	No
Pigment Violet 19	Yes	Maybe	Maybe
Pigment Orange 64	Yes	No	No
Pigment Blue 15:3	Yes	Yes	Yes
Pigment Green 7	Yes	Yes	Yes

Figure 1. Visible spectrum reflectance curve of a blue pigment

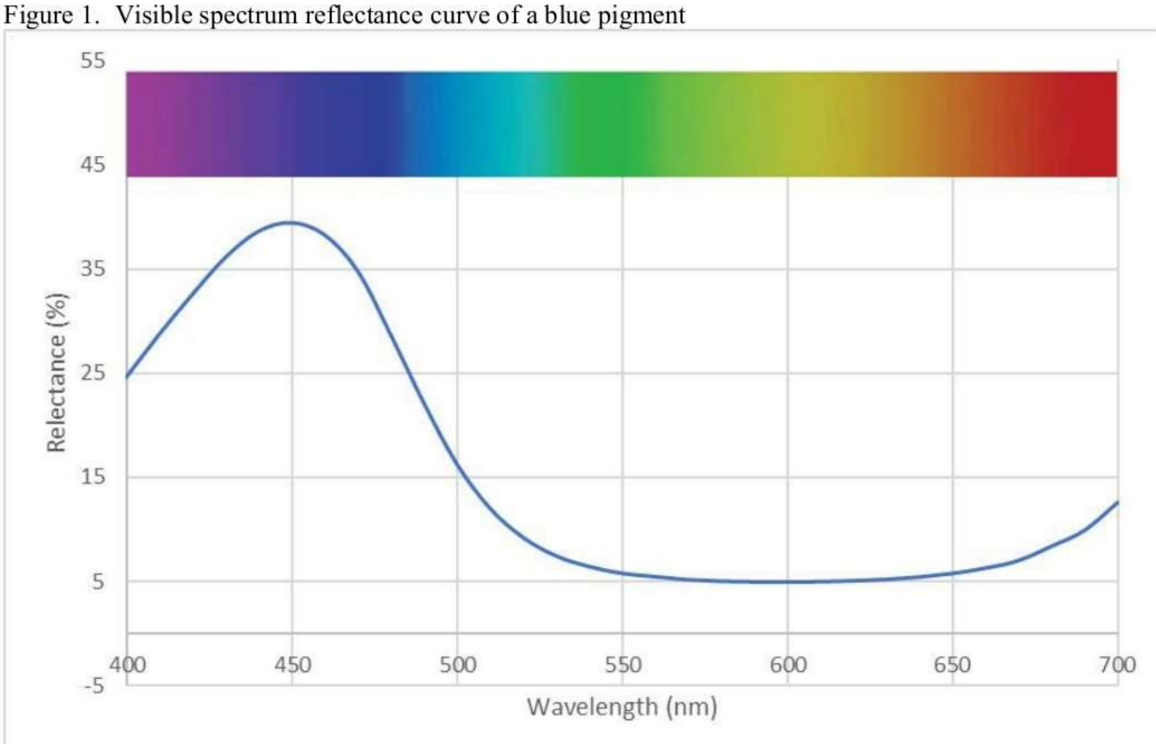


Figure 2. Spectral curves of a yellow, blue and their combined green

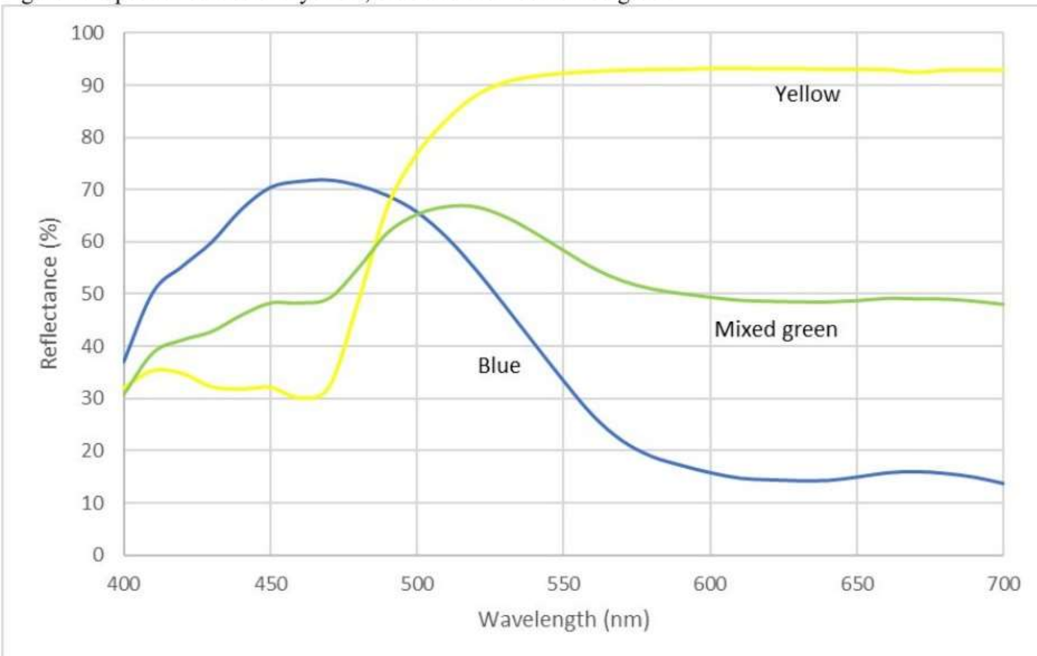


Figure 3. Spectral curves of a single pigment green and a blue/yellow mixed green

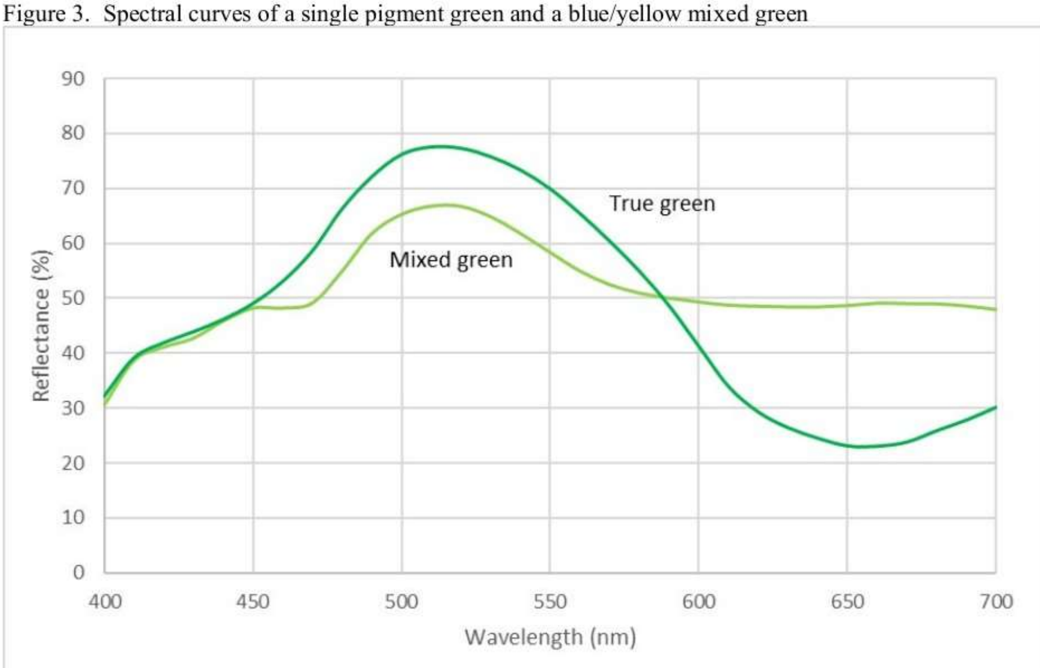


Figure 4. Spectral curves of white and black pigments

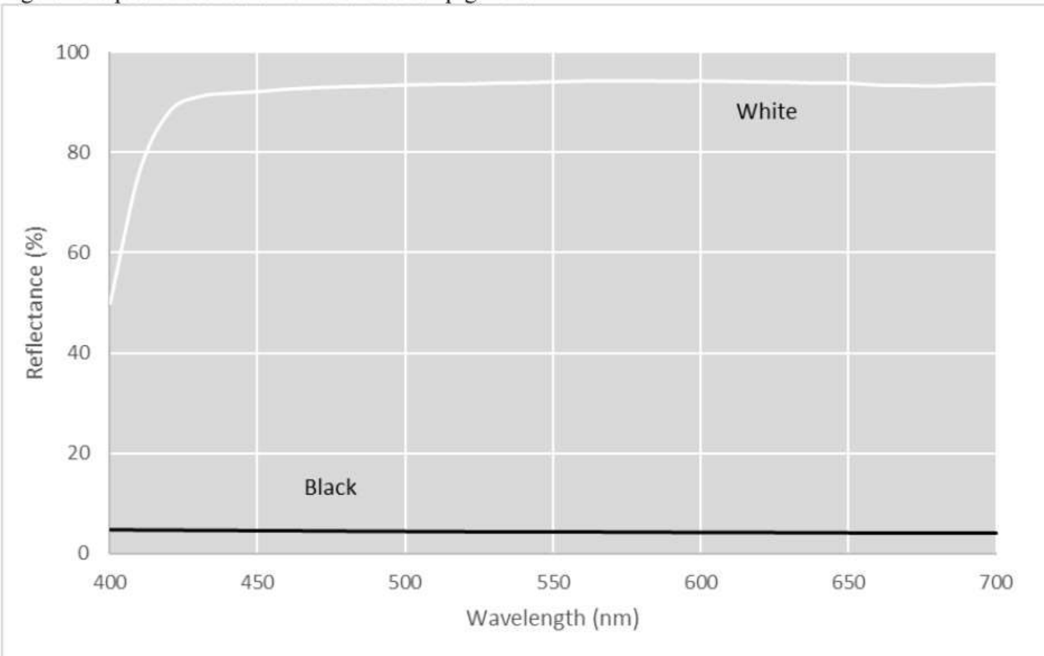


Figure 5. The effect of adding black pigment to a brown color

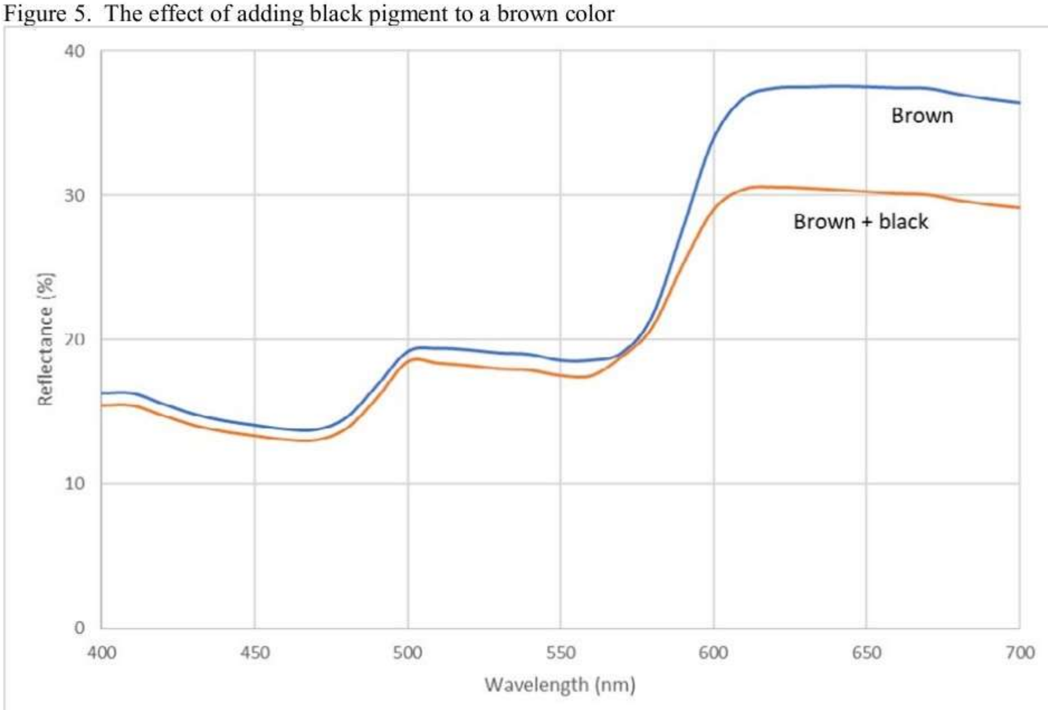


Figure 6. Darkening a brown by adding 40% more non-white pigments

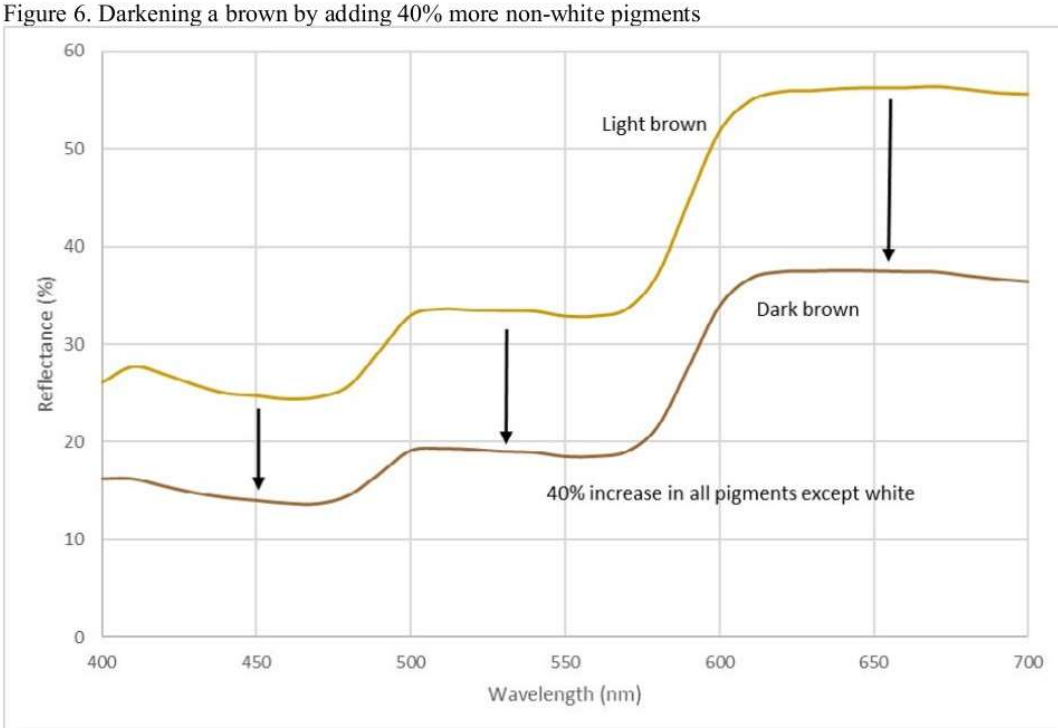


Figure 7. Two-dimensional CIE color space. Taken from *https://sensing.konicaminolta.us*.

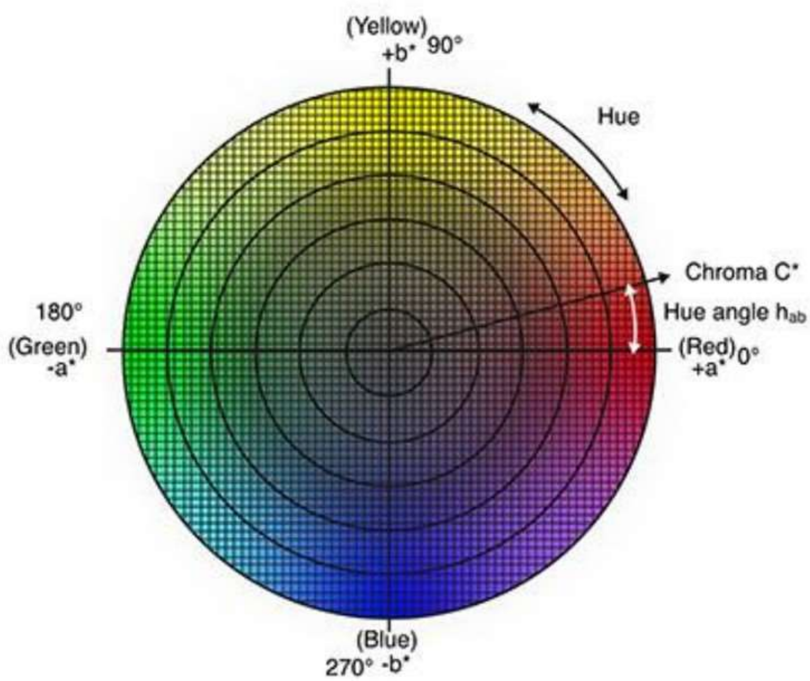


Figure 8. Illustrating C* and h in CIE(1976) a*b* color space

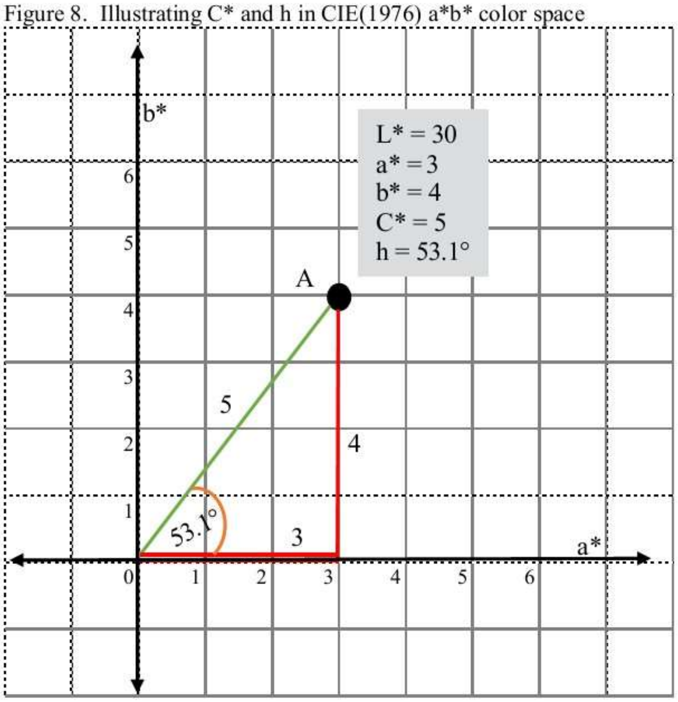


Figure 9. Color position of an organic red pigment at various concentrations in CIE C*h space

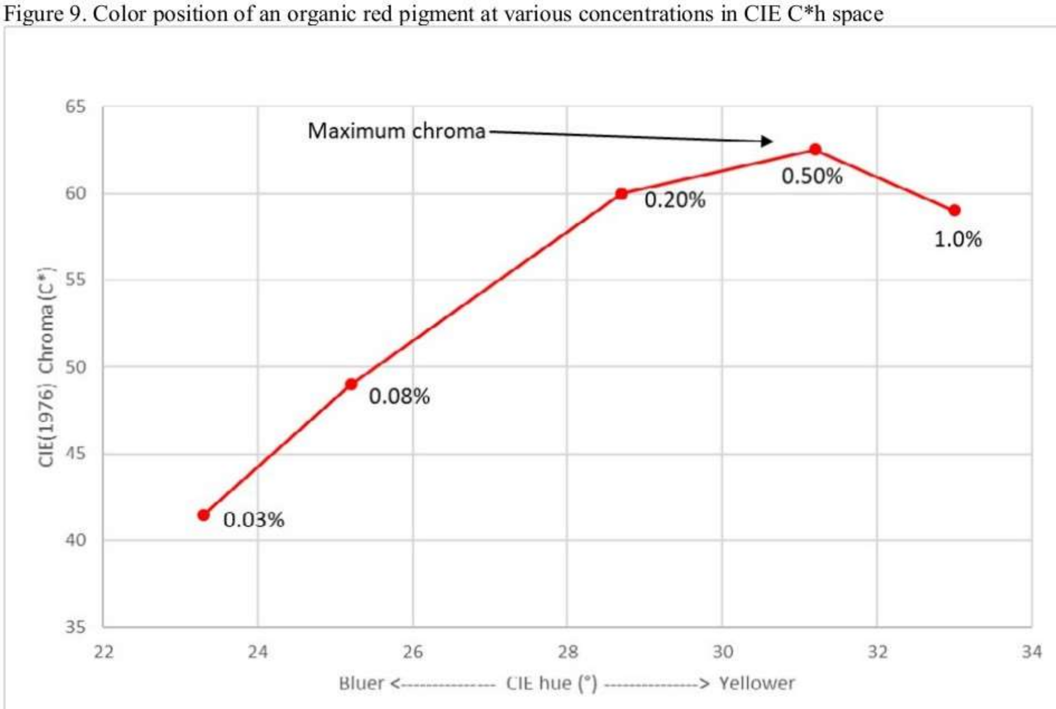


Figure 10. Color position of an organic red pigment at various concentrations in CIE C*h space

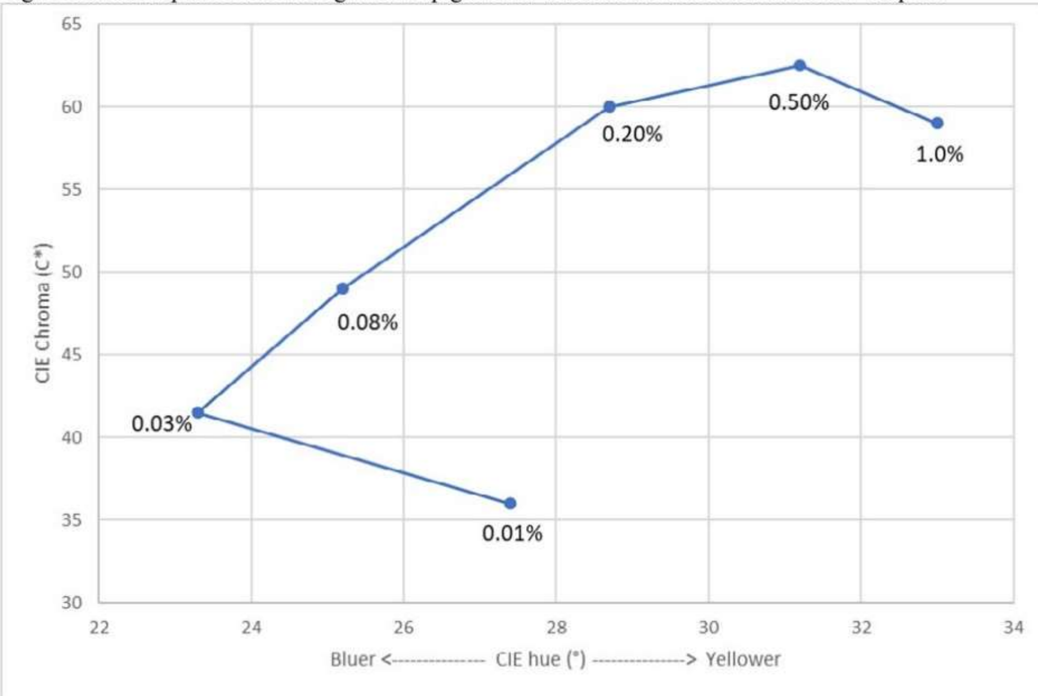
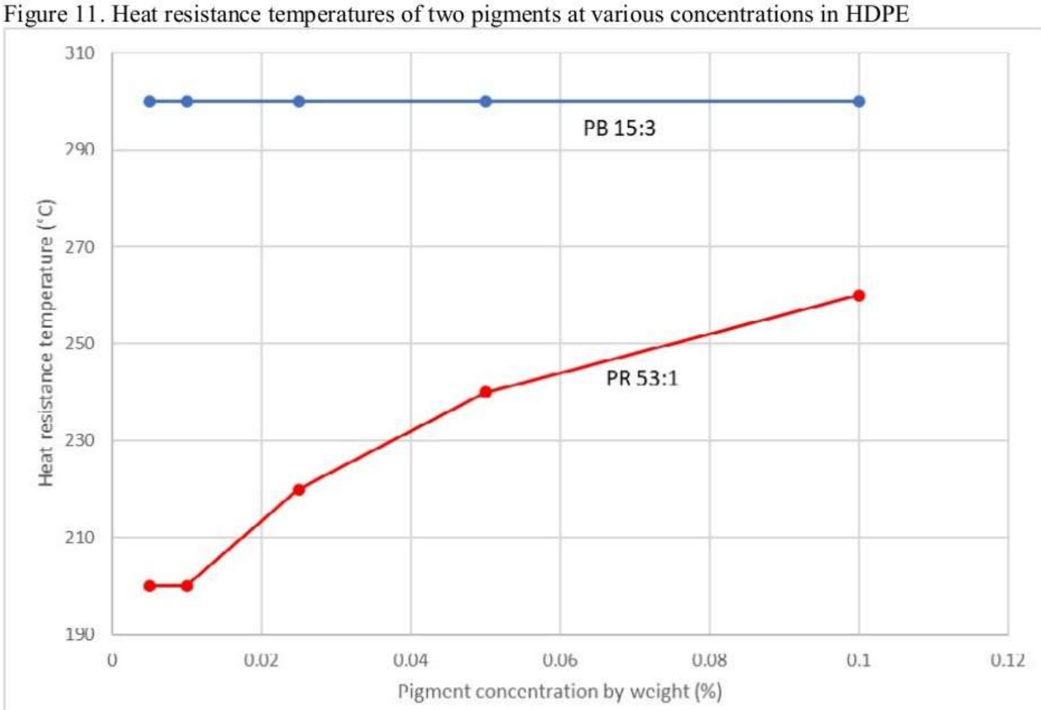


Figure 11. Heat resistance temperatures of two pigments at various concentrations in HDPE



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