Workhorse pigments for food contact plastics

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Abstract

This paper is intended to provide a summary of the common pigments that should form the core toolbox of any colorist working on food contact applications.

The paper starts by examining the core reasons to color a polymer in the first place then showing the wide range of polymers and processing techniques.

The key color chemistries are detailed along with the key criteria and performance characteristics to allow optimum selection focusing on extrusion and blow molding applications.

The relevant FDA requirements are examined and an example of pigment selection decision making is given demonstrating the relevant cost benefits of correct pigment selection for the application, before moving on to detail the core organic and inorganic pigment chemistries which are FDA compliant.

These chemistries are then examined on a cost / performance basis to illustrate the wide variation available and to function as a reference chart for the pigment selection decision making process.

Effect pigments are listed by chemistry as the range of these is too wide to cover in more detail.

The limitations applicable to FDA compliance are then examined and discussed with regards to the restrictions applicable to the color formulator.

A comparison of typical properties for inorganic and organic pigments compares and contrasts these pigment types.

An example of the decision-making process follows demonstrating how optimum pigment selection for a particular application can have a significant effect on the cost of the colorant package.

The paper wraps up with a summary of the core pigment chemistries.

Why Color Polymers?

Natural polymers vary from transparent, through translucent white to opaque yellow in color, but are also apt to vary considerably in color dependent on producer, additives and processing conditions.

Whilst many polymers, particularly engineering polymers, are used in their natural form many are used in colored form.

There are several reasons for this:

Visual identification such as different colored chopping boards for different foods to reduce the risks of cross contamination in food preparation.

Branding is paramount in any industry and brand colors are key to this supporting the value and perception of performance of a particular brand. Brand colors are immediately recognizable, vigorously promoted and protected.

Pigments are used as part of the protection package for polymers giving visual and UV opacity, enhancing weatherability / lightfastness, polymer longevity and also providing protection for the contents of any packaging. This is particularly important in food and drug packaging where UV can have a severely detrimental effect on the contents of the packaging, reducing the lifespan and increasing spoilage and waste. The thermal stability of the pigment is important as it must be capable of withstanding the temperatures the polymeric material is being processed at.

Colors are often associated with particular emotions such as red for passion whilst green is calming and blue is seen as cold. However, color is also used to indicate levels of danger with red perceived as dangerous whilst amber is neutral and green is safe.

Whilst coloration of polymers appears relatively straightforward on the surface, the wealth of different polymers and processing techniques in common use starts to complicate the decision-making process to identify the best pigments for a particular application.

When you consider the combinations of polymers and processing techniques, along with the associated performance and cost criteria then the potential combinations expand exponentially and are only restrained by the stability of the pigments in particular combinations.

This is further complicated when formulating products which are either included within food or in contact with foodstuffs, where a complex selection of regulations and restrictions are also applicable.

I remain in awe of colorists, who are routinely charged with selecting the optimum color solutions to maximize performance, across a huge range of polymers and processing techniques, whilst minimizing costs.

This paper attempts to present the key color chemistries for the particular application of food contact packaging, highlighting the typical decision-making process to get to a cost-effective solution with a practical example

Pigment Selection Criteria

As we start the process of pigment selection for food contact applications then the first step is to understand the key properties for the particular application.

Top of the list needs to be regulatory compliance, which will vary with polymer / end application and is usually defined by the customer, but in many cases the customer is not fully aware of all relevant restrictions and then the onus for correct selection falls back on the colorist utilizing either prior knowledge or research.

Second on the list is usually cost effectiveness as many food contact applications are for single use or cost sensitive products. Cost effectiveness is not simply a matter of $/lb, but of cost in use. For example a pigment which is twice the cost, but three times the strength of another is often cheaper in use when the coloring cost is calculated. The same can be said if different polymers or processing techniques can be utilized with a particular pigment selection.

Dependent on the polymer and processing technique then warp resistance may be the next key criteria, as irregular mold shrinkage can result in leaking packages, or air penetration and spoilage.

Opacity or transparency is key in the selection and further restricts the polymer and pigment choice, as well as the processing parameters.

Color and strength consistency cannot be overlooked if a stable formulation and batch to batch reproducibility is to be maintained for efficient production. There is nothing worse than looking down a shelf of finished products and spotting a variation in shade especially where brand colors are concerned.

Heat resistance requirements are defined by the polymer and processing technique that will be used in the final article. Here it is key to bear in mind that heat resistance is both time and temperature dependent. This is usually expressed as the maximum temperature at which a color change of <3 delta E units is seen in 5 minutes at temperature. A color change may exceed that delta E value at a lower temperature if the time at temperature is extended. The whole exposure time needs to be taken into account when formulating – masterbatch, initial and post processing to make the article and then potentially post sterilize. Heat resistance often varies dependent on the polymer in use.

Weatherfastness is not normally a key requirement of food contact applications, but lightfastness usually is. Identification of this at an early stage precludes certain chemistries.

Dispersibility can show up in two key ways – lumps / pits / failure points in the article itself, but also in pigment utilization. A more readily dispersible pigment will have higher color strength compared to the same pigment with poor dispersibility, often requiring less pigment to achieve the same shade / opacity / intensity.

Solvent resistance does not just relate to alcohols, gasoline, etc., but also less obvious solvents such as water, fats, oils and plasticizers and can lead to color change and/or bleeding into the foodstuff or into surrounding objects in contact with packaging.

Migration resistance / bleeding is defined as the movement of one substance from one substrate into another in contact. It is often tested by placing a colored polymer sheet in contact with a white sheet and placing these in an oven at elevated temperature and under a steady pressure (weight) to ensure a reliable contact. If the white sheet takes on any color then bleeding has taken place. A real example would be where a cheese block takes on the yellow of the packaging even though it is refrigerated in storage. Bleeding is polymer and concentration dependent as well as temperature dependent.

Pigment density varies mainly between organic and inorganic pigments, but as the formulations are normally calculated by weight the relative amount of colorant available to provide color and opacity is determined by the pigment density. The final part weight is affected to a lesser extent, but when millions of articles are involved, then this can start to add up.

Acid / alkali resistance is important because many foodstuffs can be significantly acid or alkali, potentially causing color change over a period of time.

Regulatory Compliance

In the USA regulatory compliance for food contact articles is carried out by the Food & Drug Administration (FDA)[1], but FDA compliance has become a global standard with most countries taking this a definition of "safe" for use, despite each country or region having its own regulatory compliance programs.

For example, in the European Union, then the Council of Europe Resolution AP89(1)[2] has a similar function, but individual countries also apply separate regulations on a country basis, which makes for a very complicated system.

The Food and Drug Agency in the USA makes the following statements:

Food Contact Substance (FCS) for Polymeric Articles

Persons who market an FCS based on an effective notification must be able to demonstrate that the notification is effective for their food contact substance.

All persons who purchase a food contact substance manufactured or supplied by a manufacturer or supplier identified in an effective notification may rely on that notification to legally market or use the food contact substance for the use that is the subject of the notification, consistent with any limitations in that notification.

The relevant regulations have changed in recent years.

Originally the Code of Federal Regulations (CFR) Title 21 was defined by Chemical Index (C.I.) & / or CAS number, Intended Use & Limitations.

These were then notified by use – Direct (in food) / Indirect contact (in contact with food)

21 CFR Part 178.3297 "Colorants for Polymers" 4.1.13

More recently the requirements have been modified and now when an application for a food contact approval is made it will result in a Food Contact Notification (FCN)

This is defined by Chemical Index (C.I.) & / or CAS number, Manufacturer, Intended Use & Limitations.

The fundamental difference between a CFR registration and an FCN registration is that the FCN approval is restricted to the manufacturer, manufacturing route, site and CAS number as well as the usual intended use and limitations.

Previously CFR 21 compliance was based primarily on color index and / or CAS number, which meant that once a color index had been registered then all manufacturers of that color index could claim compliance for their products. Whilst the chemistry is the main defining feature, there can be significant variations in the purity / residual intermediates in a product from different manufacturers.

The FCN registration attempts to address this by insisting on individual registrations for each manufacturing site, however this has limited the number of registrations due to the cost involved versus the potential returns.

Food Contact Colorant Families

Inorganic

TiO2 (PW.6) – Core white pigment offering excellent opacity and bright white color, high heat stability and excellent durability at low cost.

Carbon Black (PBk.7) – Although carbon black offers outstanding opacity and color strength, there are only 2 very specialized versions with food contact registrations – Channel black and a high purity furnace black with specific limits on polynuclear aromatic hydrocarbons and benzo(a)pyrene, which makes them quite expensive and limits sourcing options.

Ultramarine (PB.29 & PV.15) – These pigments offer clean and bright shades along with good heat stability and excellent durability in both mass tone and tint shades. Their low tinctorial strength makes them very useful for color correction of light shades, but not as economic for mass tone applications

Oxides – Iron (PR.101, PY.42 (High Temp), PBl.11) & Chrome (PG.17) – These offer strong, opaque, durable shades at low cost, but are relatively dull, meaning they are often used as base colours to provide opacity in combination with an organic pigment to give brighter shades. PY.42 has to be used in it's modified high temperature form otherwise it will convert to a red shade at normal plastics processing temperatures. PBl.11 has limited heat stability which means it can only really be used in LDPE.

Zinc Ferrite (PY.119) – This offers a brighter yellow shade than the iron oxides with better heat stability, but with slightly higher cost.

Aluminum & Effect Pigments – Used to achieve metallic and pearlescent effects which are used to great effect in general packaging applications to achieve a more attractive and "expensive looking" appearance.

Organic

Phthalocyanine (PB.15, PG.7) – Core blue and green chemistries which offer excellent heat stability, durability and opacity, though the performance does decrease when used in low tints with TiO_2. The very high strength is both an advantage for mass tones and a disadvantage for tint tones and strength can be difficult to control.

Azo / Metal Azo (PY.62, PY.183, PY.191) – Core mid to red shade yellows offering good to excellent heat stability, excellent dispersibility and color strength and good lightfastness. PY.62 in particular offers an very cost effective solution for LDPE applications, where the higher heatfastness of alternative chemistries just adds cost.

Disazo (PY.95) – Excellent mid shade yellow with high performance, but at higher cost

Benzimidazolone (PY.180, PY.181, PO.64) – Bright mid shade yellow and orange offering a higher performance, but at higher cost. These pigments are more often used in PP and PET applications where other yellow chemistries start to fail.

Quinacridone (PV19) – Very strong blue shade red with very high performance in mass tone and tint, at reasonable cost / lb. The cost is also somewhat offset by the strength meaning that the addition level is normally low.

Perylene (PV.29, PR.179) – High temperature violet, but with high cost and lower strength than the PV.19, so used in high temperature polymers. PR.179 is a semitransparent maroon shade with high heat stability mainly used in styrenics

Anthraquinone (PR.177) – A transparent, non-warping blue shade red used in most polymers and occasionally used in PET

Quinophthalone (PY.138) – A green shade yellow with good heat stability and lightfastness – Go to pigment for green shade yellows.

Isoindolinone (PY.110) – Semi opaque red shade yellow with excellent heat stability and lightfastness which has wide us across most polymers.

DPP (PR.254) – Very opaque medium shade red which is now the go to mid shade red for most plastics apart from polyamide. Excellent performance / cost ratio.

Effect Pigments

Many packaging applications use effect pigments to add value and stand out from the crowd. There are a limited range of FDA compliant pigments available

Aluminium pigments

Natural pearlescent pigments – 3% maximum addition by weight of polymer (21 CFR 170.39)

Synthetic pearlescent pigments – 3% maximum addition by weight of polymer (21 CFR 170.39)

Cost / Performance Review

When we consider a pigment it is very important that the performance is balanced against the cost in use rather than cost / lb.

In general inorganic pigments give very high opacity, heat stability and durability for low cost but they do not offer the high chroma of organic pigments. In most cases the optimum formulation will consist of a combination of pigments with inorganics providing the base opacity in some.

The main consideration in color matching should be to formulate according to the key criteria defined by the application and customer’s needs. For example, very high heat stability pigments would be over specified for an LDPE application, but high lightfastness could also come with additional heat stability.

Table 1 attempts to summarize the key factors by shade and heat stability, along with the processing temperatures associated with the main polymers used in food contact applications.

Table 1

Temp °C °F	Green Shade Yellow	Mid Shade Yellow	Red Shade Yellow	Orange	Yellow Shade Red	Blue Shade Red / Violet	Blue	Green	Black	White
200 390									PBk.11*	
240 460		PY.62	PY.42*							
260 500	PY.138		PY.119*			PR.177				
280 540		PY.95 PY.180								
300 570			PY.110 PY.181 PY.183 PY.191	PO.64	PR.254	PR179 PV.19 PV.29				
>300 >570					PR.101*	PV.15*	PB.15 PB.29*	PG.7 PG.17*	PBk.7	PW.6*

Low Cost **LDPE 160 °C – 220 °C (320°F – 430°F) PS 190 °C – 280 °C (380°F – 540°F)**
Medium Cost **HDPE 180 °C – 300 °C (360°F – 570°F) PET 270 °C – 310 °C (520°F – 590°F)**
High Cost **PP 200 °C – 300 °C (390°F – 570°F)**
Inorganic (*)

Limits / Restrictive Clauses

Most pigments are only compliant with the FDA regulations at a maximum level of 1% addition by weight of polymer, which means that it can sometimes be difficult to obtain the required level of opacity at the thinner wall thicknesses associated with blown bottles or thermoformed sheets.

This can be a limiting factor for inorganic pigments due to their low strength and high density, though in some case the inorganic pigments have higher addition limits, for example, PG.17 has a limit of 5% addition and PY.119 has a limit of 2% addition.

PY.62 is limited to an addition level of 0.5%

DCC LANSCO is the only supplier globally with an FDA compliant PY.62 that offers customers a more economical alternative to PY.138 Y& PY.191.

PY.138 is limited to applications with a maximum filling temperature of 158°F, 70°C

Some pigments, such as PB.29, also need to meet specific purity requirements (21 CFR 73.2725)

General Comments

Inorganic pigments

High heat stability – PY.42 is an exception as FeOOH dehydrates to Fe_2O_3 above 160ºC unless special coated heat stable grades are used which extends the heat stability to 200ºC.

Low tinctorial strength – This can be an advantage for color correction of lighter shades as it allows greater room for errors in weighing.

Lower chroma colours – This is often a disadvantage for packaging applications as brighter shades are more eye catching.

Good chemical resistance – Often very useful for food packaging

Non warping – Advantageous in more crystalline polymers such as HDPE and PET

Excellent weatherfastness / lightfastness in mass tone and tint

Easy to disperse – Maximum strength is readily achieved and with it comes color control.

Usually relatively low cost / lb

Organic pigments

Wide range of heat stabilities – Careful selection is required to manage costs

High tinctorial strength – Works well with the restricted addition levels associated with FDA compliant products

Highly chromatic shades – These grab attention in application

Careful selection required for warpage and chemical resistance – Mainly related to HDPE and PET.

Generally good weatherfastness / lightfastness in mass tone, but usually worse in tint – The importance of this depends on the design lifespan of the product.

Some pigments need high intensity mixing and compounding to disperse fully – This can sometimes cause color variations when scaling from lab to production equipment or from one process to another, but modern compounding techniques and longer high speed extruders have reduced this problem now.

Easy disperse grades are available for many chemistries – These help to reduce the effects above, but often add costs, so are only used when absolutely necessary.

Wide range of costs / lb dependent largely on performance.

Formulating Example

Example key requirements – Mustard bottle

Low cost
Single use application
Structurally robust
Limited lightfastness – no weatherfastness
Colour – bright mid shade yellow

Decision making process

Polymer – LDPE
Processing temperature – 160ºC to 220ºC
Process – Extrusion blow moulding
Relatively thin wall (and variable thickness)
Little risk of crystallization
Potential to bleed

Pigment selection

Bright shade favors a primary mid shade yellow over a blend.

Discounted:

PY.42 (too red and too dull)
PY.138 (too green)
PY.119 (too red and too dull)

Options:

PY.95
PY.180
PY.62
All meet the shade and heat stability requirements
All meet the bleed requirements
All meet the opacity requirements

Table 2

Property	PY.62	PY.180	PY.95
Chroma	**High**	**High**	**High**
Colour strength	**Outstanding**	**Outstanding**	**Outstanding**
Opacity	**Excellent**	**Excellent**	**Excellent**
Bleed resistance	**4-5**	**4-5**	**4-5**
Lightfastness	**6-7**	**6-7**	**7-8**
Chemical resistance	**3-4**	**5**	**5**
Heat stability	**240oC / 460oF**	**290oC / 550oF**	**280oC / 540oF**
Warpage	**2**	**1-2**	**1-2**
Cost	**1**	**2.5**	**5**

Conclusions

All 3 pigments will function well in this application

PY.180 and PY.95 are over specified in terms of heat stability

PY.180 and PY.95 would result in a more expensive solution

PY.62 is the perfect choice meeting the requirements for minimum cost, some 5 times cheaper pigmentation than using PY.95 and almost 1/3rd the cost of using PY.180.

(note, for the purposes of this example shading components have been ignored for reasons of simplicity)

Final Note

All finished articles need testing for conformance to FDA requirements. This applies even if all components in the article already have individual FDA compliance and all associated limits have been observed.

It is not sufficient to assume that the components are compliant, therefore the final article will be compliant, as interactions may change the behavior of mixtures.

Summary of Key FDA Colorant Families

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Carbon Black (PBk.7) – Only very specialized grades
Ultramarine (PB.29 & PV.15)
Oxides – Iron (PR.101, PY.42 (High Temp), PBl.11) & Chrome (PG.17)
Zinc Ferrite (PY.119)
Aluminum & Effect Pigments

Organic

Phthalocyanine (PB.15, PG.7)
Azo / Metal Azo (PY.62, PY.183, PY.191)
Disazo (PY.95)
Benzimidazolone (PY.180, PY.181, PO.64)
Quinacridone (PV19)
Perylene (PV.29, PR.179)
Anthraquinone (PR.177)
Quinophthalone (PY.138)
Isoindolinone (PY.110)
DPP (PR.254)

References

1. https://www.fda.gov/food/food-ingredients-packaging/packaging-food-contact-substances-fcs
2. https://rm.coe.int/16804f8648