COLORANTS FOR PLASTICS

1. Introduction

Color has been important to society since the beginning of time. From cave walls that told stories of past life to today's automobiles color has influenced the lives of every person on earth. In fact, even those who are color deficient or totally color blind are influenced and/or make special accommodations for color or their lack of the ability to perceive color. We control our movements on the roadways when encountering a traffic light that shows green, yellow, or red. The color blind person even though being unable to distinguish green, yellow, or red will make judgments on the basis of the lightness or other cues he/she sees and then makes decisions to go or stop. Therefore, color impacts every one of us regardless of our individual capabilities and/or disabilities. In the final analysis, we chose the color of our homes, in and out, the clothes we wear, the cosmetics we use, the automobiles we drive, the art we collect, the people we chose to associate with, and the places we chose to live all on the basis of how we decide on colors. We chose products or objects of various colors because we like them!

Once over the hurdle of color for its pleasure and appearance, the issue becomes one of performance and economics. Any color system in any product for industry and/or commerce must first be able to withstand the fabrication of the product. Next, the product must be able to endure the requirements of its end use environment for the designed life of the product. Finally, the economics must be such that the desirable products in the marketplace are within the economic reach of the consumer.

This brings us to the essence of coloring and colorants. Incorporating colorants into plastics may be illustrated by saying that the colorants must meet "zero or no reaction chemistry". If any chemical reaction takes place any time in a products fabrication and/or lifetime a color change is most likely to take place and the product will have failed to meet its technical and commercial design objectives.

Historically, colorants are divided into three distinct groups: organic pigments, inorganic pigment and soluble dyes. One can make the general distinction that pigments are particulate materials that should remain physically unchanged in a plastic system. Soluble dyes, on the other hand, go into solution in the plastic system, are at the molecular level, and have no particulate identity. Unfortunately, this distinction is not as clear-cut as one would like. Inorganic pigments are thought to be inherently insoluble. Indeed, most organic pigments are essentially insoluble. However, there are situations where under very specific circumstances an organic pigment may become soluble or partially soluble causing product failure. Soluble dyes to perform properly must be totally soluble in the plastic system to be effective and meet their design criteria.

The following are definitions refined from numerous sources and modified to reduce the definitions to plain words, which are understandable. These definitions are not posed to be scientifically and in totality exact since some liberty was used to make the definitions understandable to the novice reader. They are posed only to give the reader an initial understanding of what these materials are.

1.1. Organic Pigments. An organic pigment is made up of carbon, hydrogen, oxygen, and sulfer and nitrogen in combinations of atoms bonded together. Sulfur, chlorine, bromine, fluorine, calcium, strontium, barium, and manganese may also be present. The molecules are crystalline in nature and selectively absorb light to provide color. The organic pigment must remain in particulate form to perform its color functionality.

1.2. Inorganic Pigment. An inorganic pigment is made up of a combination of metalloid or metallic elements combined with oxygen, sulfur, and/or selenium. The molecules will selectively absorb light to provide color. The inorganic pigment must remain in its original particulate form to perform its color functionality.

1.3. Soluble Dye (Dyestuff). Soluble dyes dissolve in the plastic system losing any crystalline characteristics and operate at the molecular level. Since soluble dyes properly dissolved in a system have no particulate characteristics they impart color only through selective absorption. The soluble dye must be 100% in solution to perform as designed.

These truncated definitions should bring one to the conclusion that pigments can vary from almost transparent (slightly hazy to translucent) to totally opaque, while soluble dyes, used properly, will impart complete transparency.

1.4. Colorant Forms. Pigments and soluble dyes predominantly leave their manufacturing sites as powders. There may be a number of intermediate steps, however, to improve value before the colorant reaches a company for fabrication into a useful consumer product.

1.5. Dry Color Pigment (Raw Color Pigment). Dry colorants are usually added to powder polymers since the particle sizes of the powder polymers and the dry colorants are reasonably close together. The dry colorants would be added as single colorants and/or blends of dry colorants formulated to match a target color. This is a significant consideration as adding a powder colorant to pellets, cubes, or other much larger polymer granules may lead to separation during processing resulting in streaks and nonuniform color. Maximizing the efficiency of the dry colorant is also an important issue. The ability to disperse dry colorants uniformly and totally during the final fabrication step is difficult to impossible. A preliminary cost calculation may tend to indicate economies with this approach, however, additional costs are most likely to occur through rejected parts, difficult color control, and other processing issues that will consume any projected economies.

2. Dispersions

2.1. Dry Color Concentrates. Colorant dispersions are designed to provide highly efficient colorant use and uniformity of color in fabricated plastic products. The colorant dispersions bring value added effects to the plastics processes avoiding many of the problems associated with dry colors. The unit cost of colorant materials will be higher, but the finished product or system cost usually is lower and results in a superior product. Dispersions for plastics fall into two definite categories. They are solid pellets of various sizes and shapes, and liquids or pastes. The solid dispersions are further divided into cube pellets (~1/8 to 1/4 in.), spherical pellets (~1/8 in. diameter), microbeads (~1/64 in. or smaller in diameter), and cryogenically ground material (random shapes of various very small sizes). The most popular method to process these materials is twin-screw corotating compounding extruders. Other methods are also utilized such as single screw compounding extruders, Banbury high-intensity mixers, and continuous high-intensity mixers. Liquid dispersions, on the other hand, are colorants dispersed in a liquid vehicle that is part of the plastic system or is compatible with the system. Organic colorants can range from ~20 to 60% in dry concentrate while inorganic colorants can range from 50 to 85%. Soluble dyes in dry concentrates will usually range between 15 and 30% colorant loadings. Particular situations may suggest ranges outside these generalized loadings for uncommon special situations.

No matter the equipment used, the dispersion process must accomplish a number of tasks. First is distributive mixing followed by dispersion of the colorants. The dispersion process is designed to break up agglomerates of loosely held colorant particles, reduce aggregates of tightly held particles as much as possible (1), and remove adsorbed air from particle surfaces (2) (Fig. 1).

Care must be taken since the assumption that more dispersion energy is better may not produce the best product. Two issues should be considered. If additional color intensity or strength results from more dispersion energy input, the colorants have not been dispersed and developed in the original dispersion step. If a hue, chroma, and value change results from additional dispersion energy, pigment degradation and/or an unwanted chemical reactions occur both of which indicate the processing conditions are to severe. In almost every instance, all three; hue, chroma, and value will change at the same time. It is possible as the dispersion process goes forward the color properties will increase. However, it is possible to overdevelop or disperse colorants to the point that the color value will decrease.

2.2. Liquid Colorant Concentrates. Liquid color concentrates play the same role as the dry concentrate using a different method to introduce colorants into plastics. The two significant differences are that the carrier is a liquid rather than a solid polymer. The liquid vehicle opens the door to an entirely different dispersion technique. Dispersion can be very intense and superior to the dry color concentrates in terms of reducing aggregates and agglomerates.

Loadings in liquid colorant concentrates can range from as low as 20% to as high as 95%. The methods for obtaining these high loadings of colorants are high intensity rotating disk dispersers; sand mills, and three roll ink mills.

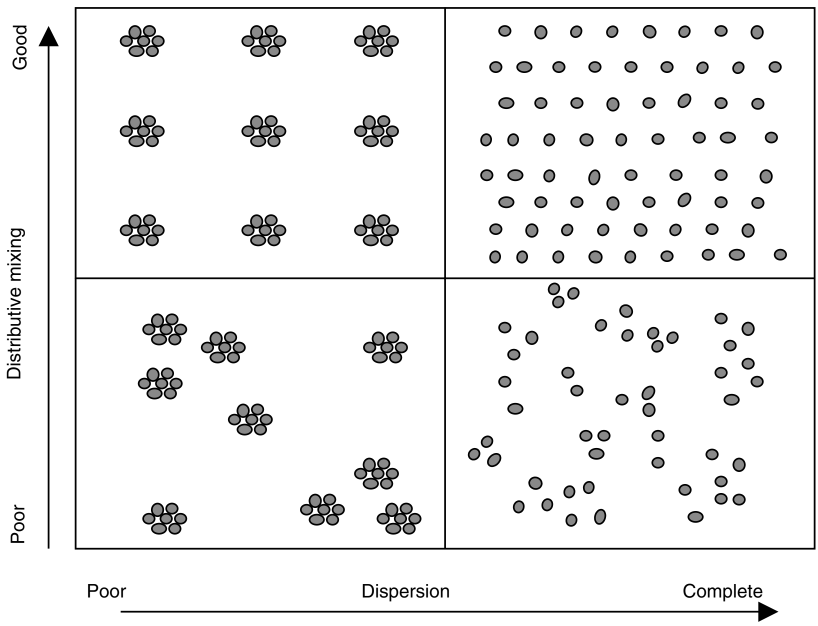

Fig. 1. Distributive mixing versus dispersion.

The potential for very high loadings in liquid colorant concentrates may lead to cost savings per unit product produced (Fig. 2).

3. Colorant Properties

The properties of colorants can have a profound impact on the plastic being colored. There are a number of general property issues that should be considered each and every time an individual colorant is added to a system. General summaries of these properties are covered here.

1. *Dispersibility*. Colorants must be able to be uniformly dispersed in any plastic system. If the system is unable to tolerate the shear energy required to disperse a given colorant, no matter how desirable the colorant may be, it is not usable in that system. Dispersed colorants as solid or liquid concentrates may provide the avenue to use colorants not meeting the initial dispersion requirements.
2. *Lightfastness*. Lightfastness is a function of exposure to ultraviolet (uv) and possibly visible (vis) radiation and humidity, but no contact with liquid water. A rule of thumb description might be to think of lightfastness as indoor exposure.
3. *Migration*. Migration is defined as the movement of particulate colorants or additives in a finished product. Even though many assume a particulate material is "locked in" in a solid plastic, movement can take place when

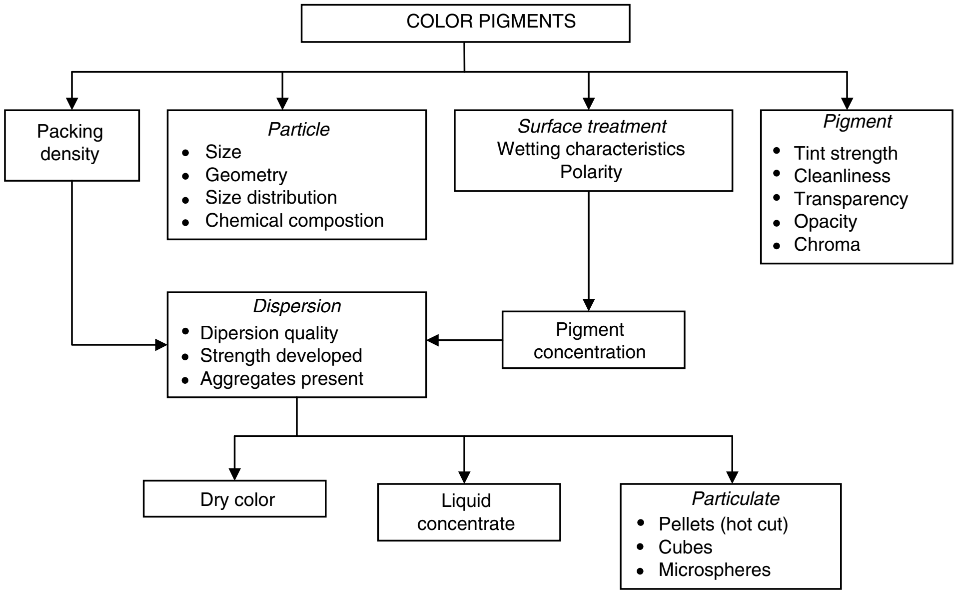

Fig. 2. Physical and dispersion properties of pigments.

conditions permit. This mobility is thought by some to be blooming and/or bronzing. Usually, it can be detected over time by the presence of a metallic appearing dry film on the surface of a part, which can be mechanically removed.

4. *Chemical Resistance*. Chemical resistance means the colorant(s) do not get involved chemically or react in any way as a result of mechanical mixing, heat, shear energy, attack by chemicals externally applied, uv, vis, infrared (ir) radiation, gases, aerosols, or any miscellaneous items. Any time a colorant and/or additives in a plastic system are active chemically, a color change can be expected. Therefore, the goal is to have the colorants function without being chemically active.
5. *Blooming*. Blooming is sometimes called sublimation. It usually involves low molecular weight colorants that literally evaporate out of a plastic system then condenses on the surface of the plastic product. This condensate can usually be removed mechanically. The process is one that takes place over time.
6. *Toxicity*. This issue is easy to declare, but difficult to achieve. Unanimity of which colorants are toxic to society is difficult to obtain since opinions vary widely. It can be said that no colorants or combination of colorants should present a danger to health during manufacture, processing, and fabrication, or during the life cycle of the product.
7. *Solvent Resistance*. Colorants must resist attack by solvents, which might cause them to partially or totally go into solution. If this happens there is usually a color change accompanying the solubility. Many organic pigments and, of course, soluble dyes are subject to this phenomenon.

It should be noted that unexpected solubility of colorants may come from the polymer as a solvent at normal and/or at some elevated threshold temperature. Also forgotten many times is that water is or can be an active solvent!

8. *Environmental*. This issue is one of doing nothing that results in a hazard to the world around us. It is different from toxicity, which deals with hazards to human health. There is concern that plastic products that are discarded may be harmful to the environment and the creatures and growing things that inhabit our environment. This describes just one illustration of a complex issue. For our specific purpose, the consideration is that colorants, however, they may get into the environment cause no harm to plants and animals.
9. *Compatibility*. This issue seems self-explanatory, however many misunderstand it. Some colorants, mainly organics and soluble dyes, have a negative effect on some polymers where they may be introduced. Some colorants may become soluble or partially soluble in some polymers and in other cases; eg, colorants that promote polymer degradation are issues that must be understood by the technician working with them.
10. *Batch Uniformity*. Any user of colorants may expect batch No. 10 or higher to be identical to batch No. 1. Typical manufacturing of colorants suggests making subsequent batches absolutely identical to the first batch is unrealistic. However, a tolerance can be obtained that satisfies the needs of a project. The issue here is not to demand or expect consistent uniformity beyond the capabilities of the manufacturing systems involved.
11. *Particle Integrity*. Integrity of a colorant particle refers to a colorants ability to withstand fracture during intensive dry mixing, high shear rates during compounding, and other physical abuse during fabrication. Some colorant particles are thought to be “brittle”. These colorants are susceptible to fracture anywhere during processing. If a colorant particle is, in fact, fractured, a color change will result. It may be assumed chemical degradation has taken place while in fact a mechanical problem exists. No solution is possible unless the problem is correctly identified as either a chemical or a mechanical one.
12. *Particle Size*. Colorant particle size and size distribution are paramount for color and performance. Particle size and distribution of colorants are directly related to the ability of the colorant to selectively absorb and scatter light. The ability of a colorant to scatter light results in opacity or transmission of light. The ability to selectively absorb light results in the observed color. Many applications for colorants can fail if the particle size is not well matched to design properties of the system. An example of a miss-match might be a large size particle colorant used in a fiber application. In this case, fiber breakage can be expected due to the large particle weakening a fiber since it occupies a significant cross-section of the fiber thereby making it very weak and subject to breaking. This can occur during fiber manufacture and/or during later operations.
13. *Heat Stability*. Heat stability should be understood as a time–temperature relationship. Most pigments and soluble dyes have a limit to their

endurance to heat over time. It is possible that a low temperature history over a long time may degrade a colorant resulting in a color change. On the other hand, the same colorant may tolerate a very high temperature of short duration successfully, which means no color change. Typically, technologists will test the heat stability of a colorant in a 5-min exposure at a given temperature just below where degradation takes place. It should be noted holding a colorant in a plastic machine barrel for a 5-min residence time usually does this. Note this type of testing is in the absence of air, whereas a test that exposes the colorant polymer combination to air (oxygen) may result in a totally different result. This issue is further complicated in that the results of a colorant tested in multiple plastic materials may also give widely varying results for each polymer.

14. *Weatherability*. Weatherability measures the ability of a colorant in its polymer system to withstand the effects of uv, vis, and ir radiation in the presence of heat cycling, direct contact with water, humidity, gases, aerosols, particulates, and the other pollutants occurring in an outdoor environment. These can vary significantly depending on location such as a clean mountain exposure compared to an industrial exposure with many pollutants, where some maybe unknown.
15. *Bleeding or Migration*. Bleeding, sometimes called contact bleeding, is defined as a colorant in a polymer, which is in intimate contact with a similar or different polymer due to colorant solubility moving from the initial polymer to the second polymer resulting in discoloration. This movement may be associated with noncolorant additives in either or both polymers.
16. *Electrical*. Many plastic products are designed to function in an electrical environment where the ability to conduct a charge or provide insulation properties are paramount. Colorants can have a significant effect on these properties. This can be by design or unwanted consequences. Carbon based or metallic pigments can provide significant opportunities to conduct a charge. On the other side of the issue where insulating qualities are desired, colorants can reduce the insulating properties. Many colorants contain metal salts intentionally or due to inadequate manufacturing procedures. If this is the case, the colorant can contribute to the conduction of an electrical charge. This issue is further complicated due to the recent emergence of conducting polymers. Polymeric or plastic materials that actually conduct an electrical charge at some level are commercially available.
17. *Fire Resistance*. Fire resistance addresses the issue of will colorants in a plastic increase or decrease the inherent resistance for the plastic to burn. Inorganic colorants do not contribute to the burning of plastic materials. Organic colorants are combustible in themselves. However, the contribution is usually quite small or nonexistent. One positive factor at work is that, in most cases, the amount of colorant present may be so small that its contribution is not significant. Flame and/or fire resistance is not an issue that can be ignored. In any system where fire resistance must be considered, the contribution by colorants good and bad must be accounted for.

18. *Availability*. This should be self-evident to most. Color technologists are drawn to what's new! This has its merits since the first out in the marketplace with a new and different product stands to reap benefits. However, the down side of this position is that in some cases the continued reliability of the source and the uniformity (No. 10) of the product over time needs to be closely determined. Products are removed from the market on occasion, not because the product is faulty, but because the confidence of a continuing supply of uniform colorant and/or colorant raw materials cannot be assured.
19. *Economics–Cost*. The best product in the world is useless if the market cannot afford it. Particularly in the field of coloring plastics, the colorist focuses on making the best match to meet all the requirements. Then and only then are economics and costs addressed. One should always remember that the cost of producing a colored plastic product always has the economics in the overall equation. To ignore this issue is to invite disaster.
20. *Color Values*. Color values of individual colorants play an important role. The colorist needs to understand issues such as, but not limited to, hue, undertone color, and strength. An example might be trying to match a yellow shade (undertone color) red using a blue shade (undertone color) red. Chances are under these stated conditions a close color match is unattainable. Strength of a colorant deals with just how much color is visually delivered per unit weight per unit cost. The colorist must understand and be aware of these issues if success is going to be achievable.
21. *Ease of Cleanup*. This in many cases is a minor issue. It can be important particularly in a production scenario where many color changes are made on a given production setup. Ease of cleanup has many variables, however, a combination of a low specific gravity (density) coupled with a low apparent bulk density indicates a dusty colorant. This is just one example of this issue. There are many more depending on the processes involved.

4. Organic Pigments

There are hundreds of organic pigment chemical families in commerce. Additionally, manufacturers compete with one another directly or with variations of the most popular chemical types. This makes organic pigment selection a complex process. In many cases, there is no right choice, just a choice. Therefore, basic information presented here will allow the technologist to direct colorant selection with a basic understanding of the issues involved (Fig. 3).

Table 1 lists selected organic pigments for plastics. This list cannot include each and every organic pigment that has utility in plastics. To do so would mean listing the hundreds of chemical types and the thousands of variations of these organic colorants. The list is an overview of what is possible. Individual coloring projects may have to search for similar pigments to satisfy specific requirements.

Table 2 offers and additional guide to organic pigment selection.

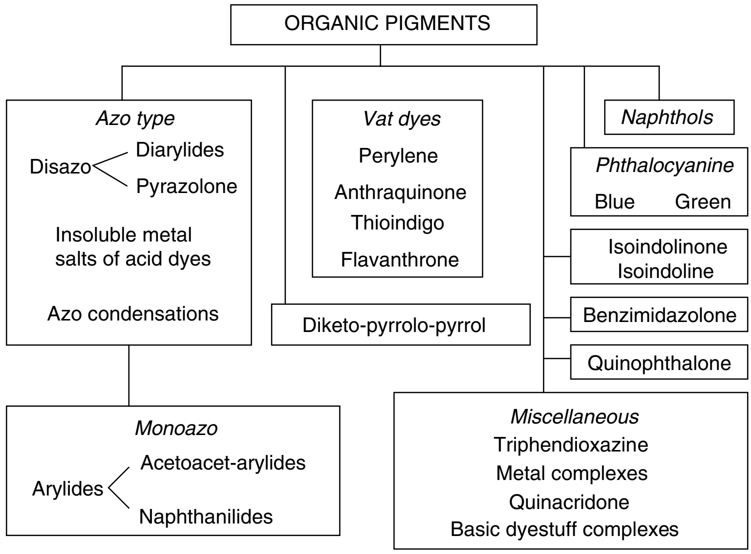

Fig. 3. Organic pigments.

Table 1. **Selected Organic Pigments for Plastics**

Colour Index name	Pigment chemical types	Colour Index number	CAS Registry number
Vat Yellow 1	Flavanthrone Yellow	70600	[475-71-8]
Vat Yellow 20	Anthrapyrimidine Yellow	68420	[4216-01-7]
Pigment Yellow 13	Diarylide Yellow AAMX	21100	[5102-83-0]
Pigment Yellow 14	Diarylide Yellow AAOT	21095	[5468-75-7]
Pigment Yellow 17	Diarylide Yellow AAOA	21105	[4531-49-1]
Pigment Yellow 62:1	Monoazo Yellow, Calcium Salt	13940:1	[12286-66-7]
Pigment Yellow 83	Diarylide Yellow 83	21180	[5567-15-7]
Pigment Yellow 93	Disazo Condensation Yellow	20710	[5580-57-4]
Pigment Yellow 95	Disazo Condensation Yellow	20034	[5280-80-8]
Pigment Yellow 97	Permanent Yellow FGL	11767	[12225-18-2]
Pigment Yellow 138	Quinophthalone Yellow	56300	[56731-19-2]
Pigment Yellow 139	Isoindoline Yellow	56298	[36888-99-0]
Pigment Yellow 150	Metal Complex Yellow	12764	[68511-62-6]
Pigment Yellow 155	Bisacetoacetarylide	N/A	[68516-73-4]
Pigment Yellow168	Monoazo Yellow, Calcium Salt	13960	[71832-85-4]
FD&C Yellow #5	Tartrazine Yellow	19140	[1934-21-0]
Pigment Yellow 191	MonoazopyrazoloneYellow, Calcium Salt	18795	[129423-54-7]
Pigment Red 48:1	Permanent Red 2B, Barium Salt	15865:1	[7585-41-3]
Pigment Red 48:2	Permanent Red 2B, Calcium Salt	15865:2	[7023-61-2]
Pigment Red 48:3	Pemanent Red 2B, Strontium Salt	15865:3	[15782-05-5]
Pigment Red 53	Red Lake C	15585	[2092-56-0]
Pigment Red 122	Quinacridone Magenta	73900	[980-26-7]
Pigment Red 123	Perylene Red	71145	[24108-89-2]
Pigment Red 144	Disazo Condensation Red	71145	[12225-02-4]
Pigment Red 166	Disazo Condensation Red	20730	[1225-04-6]

Table 1 (*Continued*)

Colour Index name	Pigment chemical types	Colour Index number	CAS Registry number
Pigment Red 168	Brominated Anthanthrone Orange	59300	[4378-61-4]
Pigment Red 177	Anthraquinone Red	65300	[4051-63-2]
Pigment Red 179	Perylene Red	71130	[5521-31-3]
Pigment Red 190	Perylene Red	71140	[6424-77-7]
Pigment Red 202	Quinacridone Magenta	73907	[68859-50-7]
Pigment Red 220	Disazo Condensation Red	20055	[57971-99-0]
Pigment Red 221	Disazo Condensation Red	20065	[61815-09-6]
Pigment Red 254	Diketo-pyrrolo-pyrrol	56110	[84632-65-5]
Pigment Red 255	Diketo-pyrrolo-pyrrol	N/A	N/A[a]
Pigment Red 264	Diketo-pyrrolo-pyrrol	N/A	[120500-90-5]
Pigment Red 272	Diketo-pyrrolo-pyrrol	561150	N/A[a]
Vat Orange 7	Perinone Orange	71105	[4424-06-0]
Vat Orange 15	Anthramide Orange	69025	[2379-78-4]
Pigment Orange 13	Pyrazolone Orange	21110	[3520-72-7]
Pigment Orange 34	Disazo Condensation Orange	21115	[15793-73-4]
Pigment Orange 43	Perinone Orange	71105	[42612-21-5]
Pigment Orange 64	Azoheterocycle Orange	12760	[75102-84-2]
Pigment Orange 71	Diketo-pyrrolo-pyrrol	561200	N/A[a]
Pigment Orange 73	Diketo-pyrrolo-pyrrol	561170	N/A[a]
Vat Blue 4	Indanthrone Blue	69800	[81-77-6]
Pigment Blue 15:1	Phthalocyanine Blue	74160:1	[147-14-8]
Pigment Blue 15:3	Phthalocyanine Blue	74160:3	[147-14-8]
Pigment Blue 15:4	Phthalocyanine Blue	74160:4	[147-14-8]
Pigment Blue 25	Napthol Blue AS	21180	[10127-03-4]
Pigment Violet 23	Carbazole Dioxazine Violet	51319	[6358-30-1]
Pigment Green 7	Phthalocyanine Green	74260	[1328-53-6]
Pigment Green 36	Phthalocyanine Green	74265	[14302-13-7]
Pigment Violet 19	Quinacridone Violet	46500	[1047-16-1]
Pigment Violet 19	Quinacridone Violet	73900	[1047-16-1]
Pigment Violet 29	Perylene Violet	71129	[12236-71-4]
Pigment Blue 60	Indanthrone Blue	69800	[81-77-6]
Pigment Violet 32	Benzimidazolone Violet	12517	[12225-08-0]

[a] NA = Not available.

5. Inorganic Pigments

These pigments are unique in that they all contain a metal in their composition. Inorganic pigments are essentially insoluble; therefore, migration and bleeding are nonexistent. Another characteristic worthy of considering is that lightfastness, weatheribility, chemical resistance, heat stability, and opacity usually come as a package. What this means is if a particular inorganic pigment exhibits excellent heat stability, eg, the chances that its other properties will probably be good to excellent as well. Note that naturally mined-oxide pigments have little or no utility in plastics since the colorant properties are inferior to the synthetic varieties. These natural colorants do find utility in some artist colors. The basic information that follows should serve as an initial guide in the usage of inorganic pigments (Fig. 4, Table 3).

Table 2. **Typical Organic Pigment Applications**

	Thermoplastics[a]														Thermoset[a]				
	GPPS	LDPE	HDPE	PP	ABS	Acrylic	Acetal	Flex. PVC	Rigid PVC	Poly-amide	Cell-ulose	Poly-ester	Polycar-bonate	Fluoro	Epoxy	Poly-ester	Phenolic	Sili-cone	Poly-urethane
Violets																			
quinacridones	L	W	W	W	L	W	L	W	L	L	L	L	N	N	L	L	L	L	L
dioxazines	W	W	W	W	N	W	W	W	W	L	L	L	N	N	L	W	L	L	W
Blues																			
phthalocyanines	W	W	W	W	W	W	W	W	W	L	W	W	W	N	W	W	L	L	W
indanthrones	W	W	W	W	L	W	L	W	W	N	W	L	L	N	N	L	L	L	L
Greens																			
phthalocyanines	W	W	W	W	W	W	W	W	W	L	W	W	W	N	W	W	W	W	W
Yellows																			
disazo condensations	W	W	W	W	W	W	L	W	L	L	W	W	N	N	W	W	L	L	L
diarylides[b]	W	W	W	W	L	L	N	W	L	L	W	W	N	N	W	L	L	N	L
flavanthrones	L	L	L	L	N	L	N	W	W	N	W	W	N	N	W	W	N	N	W
isoindolinones	W	W	W	W	W	L	N	W	W	L	W	W	L	N	W	W	W	L	W
hansas	L	N	N	N	N	N	N	N	L	N	L	L	N	N	L	N	W	L	N
Oranges																			
disazo condensations	W	W	W	W	L	W	W	W	L	N	W	W	N	N	W	W	W	W	W
diarylidesb	L	L	L	L	L	L	N	L	N	N	L	L	N	N	L	L	L	L	W
pyrazolones	W	W	W	W	L	L	N	L	N	N	L	L	N	N	L	L	L	L	W
isoindolnones	W	W	W	W	L	N	W	L	L	N	W	W	N	N	W	W	L	W	W
anthanthrones	W	W	W	W	L	N	L	W	W	N	W	W	N	N	L	W	L	L	W
diketo-pyrrolo-pyrrolos	L	W	W	W	L	L	L	W	W	N	N	N	N	N	L	L	L	L	L
Reds																			
permanent red 2B's	W	W	W	W	L	N	N	W	L	N	W	N	N	N	L	L	N	L	L
pigment scarlets	W	W	W	W	L	N	N	W	L	N	W	L	N	N	L	L	N	L	L
red lake C's	W	W	W	W	W	L	N	L	L	N	L	L	N	N	L	L	L	L	L
perylenes	L	W	W	W	W	W	W	W	W	L	W	L	L	L	L	W	L	L	W
quinacridones	L	W	W	W	L	L	L	L	L	L	L	L	L	N	L	L	L	L	L
disazo condensations	W	W	W	W	W	W	W	W	L	L	W	W	N	N	W	W	W	W	W
diketo-pyrrolo-pyrrols	L	W	W	W	L	L	L	W	W	L	L	L	L	L	L	L	L	L	L

[a] W = widely used, L = limited use (testing suggested), N = not used.
[b] Note: Diarylides may decompose when processed > 200°C (392°F), which may release toxic substances.

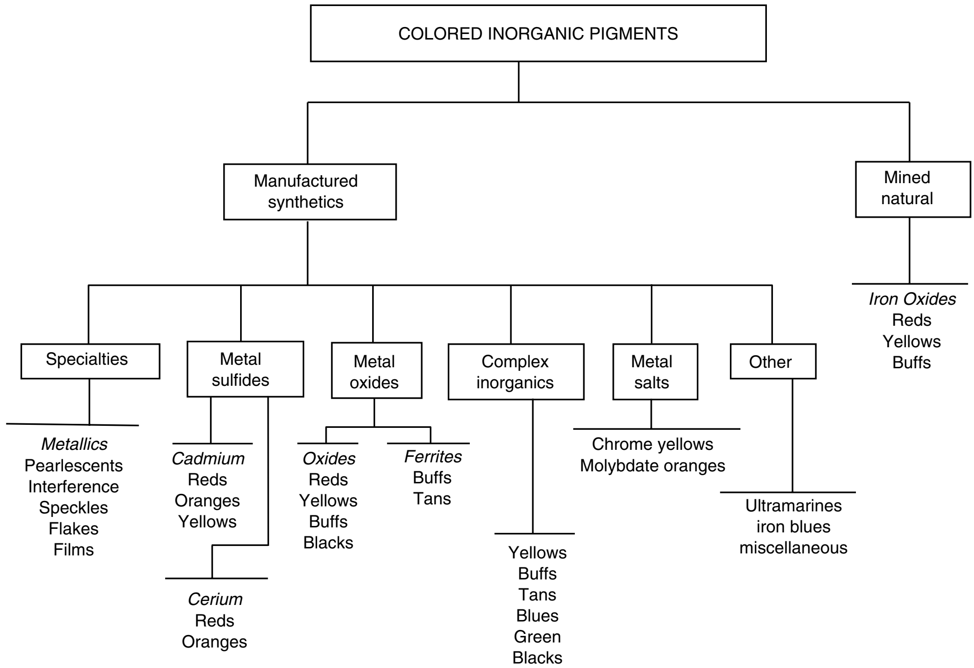

Fig. 4. Colored inorganic pigments.

Table 3. **Selected Inorganic Pigments for Plastics**[a]

Colour Index name	Pigment name	Colour Index number	CAS Registry number
Pigment Black 7	Carbon Black	77266	[1333-86-4]
Pigment Black 11	Iron Oxide Black	77499	[12227-89-3]
Pigment Black 12	Iron Titanate Brown	77543	[68187-02-0]
Pigment Black 26	Manganese Ferrite Black	77494	[68186-94-7]
Pigment Black 27	Iron Cobalt Chromite Black	77502	[68186-97-0]
Pigment Black 28	Copper Chromate Black	77428	[68186-91-4]
Pigment Black 30	Chrome Iron Nickel Black	77504	[71631-15-7]
Pigment Brown (Black) 35	Iron Chromate Black	77501	[68187-09-7]
Pigment White 6	Titanium Dioxide White (Anatase)	77891	[13463-67-7]
Pigment White 6	Titanium Dioxide White (Rutile)	77891	[13463-67-7]
Pigment Brown 6	Iron Oxide Brown	77491 and 77492 and 77499	[52357-70-7]
Pigment Brown 6	Iron Oxide Buff	77491	[52357-70-7]
Pigment Brown 11	Iron/Zinc/Magnesium Oxide Tan	77495	[64294-89-9]
Pigment Brown 24	Chrome Antimony Titanate Buff	77310	[68186-90-3]
Pigment Brown 31	Zinc Ferrite Buff	77496	[68187-51-9]
Pigment Brown 33	Zinc Iron Chromite Brown	77503	[68186-88-9]
Pigment Brown 35	Iron Chromite Brown	77501	[68187-09-7]
Pigment Brown 39	Chrome Manganese Zinc Brown	77312	[71750-83-9]

Table 3 (*Continued*)

Colour Index name	Pigment name	Colour Index number	CAS Registry number
Pigment Brown 40	Manganese Chrome Antimony Titanate Brown	77897	[69991-68-0]
Pigment Brown 45	Manganese Tungsten Titanate Brown	778965	[144437-66-1]
Pigment Yellow 34	Lead Chromate Yellow	77600 and 77603	[1344-37-2] and [7758-97-6]
Pigment Yellow 35	Cadmium Sulfide Yellow	77205	[8048-07-5] and [12442-27-2]
Pigment Yellow 37	Cadmium Sulfide Yellow	77199	[1306-23-6] and [68859-25-6]
Pigment Yellow 42	Iron Oxide Yellow	77492	[51274-00-1]
Pigment Yellow 53	Nickel Antimony Titanate Yellow	77788	[8007-18-9]
Pigment Yellow 119	Zinc Ferrite Brown	77496	[68187-51-9]
Pigment Yellow 157	Nickel Barium Titanate Yellow	77900	[68610-24-2]
Pigment Yellow 161	Nickel Niobium Titanate Yellow	77895	[68611-43-8]
Pigment Yellow 162	Chrome Niobium Titanate Yellow	77896	[68611-42-7]
Pigment Yellow 163	Chromium Tungsten Titanate Yellow	77897	[68186-92-5]
Pigment Yellow 164	Manganese Antimony Titanate Buff	77899	[68412-38-4]
Pigment Yellow 184	Bismuth Vanadate Yellow	N/A	[14059-33-7]
Pigment Yellow 189	Nickel Tungsten Titanate Yellow	77902	[69011-05-8]
Pigment Orange 20	Cadmium Sulfoselenide Orange	77202	[12656-57-4]
Pigment Orange 21	Chrome Orange	77601	[1344-38-3]
Pigment Red 101	Iron Oxide Red	77491	[1309-37-1]
Pigment Red 104	Lead Molybdate Orange	77605	[12656-85-8]
Pigment Red 104	Lead Molybdate Red	77605	[12656-85-8]
Pigment Red 108	Cadmium Sulfoselenide Red	77202 and 77196	[58339-34-7]
Pigment Red 108	Cadmium Sulfoselenide Orange	77202 and 77196	[58339-34-7]
Pigment Red 259	Ultramarine Pink	77007	[12769-96-9]
Pigment Green 17	Chromium Oxide Green	77288	[1308-38-9] and [68909-79-5]
Pigment Green 18	Hydrated Chromium Oxide Green	77289	[1201-99-9]
Pigment Green 26	Cobalt Chromite Green	77344	[68187-49-5]
Pigment Green 50	Cobalt Titanate Green	77377	[68186-85-6]
Pigment Blue 27	Ferriferrocyanide Blue (Iron Blue)	77510	[14038-43-8]
Pigment Blue 28	Cobalt Aluminate Blue	77346	[1345-16-0]
Pigment Blue 29	Ultramarine Blue	77007	[57455-37-5]
Pigment Blue 36	Cobalt Chromite Blue	77343	[68187-11-1]
Pigment Blue 36:1	Zinc Chrome Cobalt Aluminate Blue	77343:1	[74665-01-3]
Pigment Blue 72	Cobalt Zinc Aluminate Blue	77347	[68186-87-8]
Pigment Violet 14	Cobalt Phosphate Violet	77360	[13455-36-2]
Pigment Violet 15	Ultramarine Violet	77007	[12769-96-9]
Pigment Violet 16	Manganese Violet	77742	[10101-66-3]
Pigment Violet 47	Cobalt Lithum Phosphate Violet	77363	[68610-13-9]

[a] Note: Some colorants have multiple entries for Colour Index and CAS Registry Numbers. Variations within the colorant chemistry account for these multiple entries.

Table 4 offers usage information to act as an initial guide toward inorganic pigment selection.

6. Soluble Dyes

Soluble dyes present a unique situation to the colorist. There are many chemical types of soluble dyes to choose from similar to organic and inorganic pigments. The different types add confusion as most chemical types of dyes deliver a full range of colors. This full range is available in each chemical type that figuratively covers the entire visual color spectrum. Therefore, soluble dye selection is critically and fundamentally based upon what chemical type performs the best in a system and the target color desired. This is not to say these issues are not important for organic and inorganic pigments. They are a distinct issue that comes with soluble dyes is that they, by being soluble in a polymer system, are totally transparent. This difference brings to bear a visible difference not enjoyed by pigments, which have some translucency or opacity. Simply stated; pigments scatter some light, soluble dyes do not (Fig. 5).

Figure 5 displays the wide range of soluble dye chemical type available. Only a selected number from this list make up the major usage, which simplifies the selection issues.

Widely used solvent dye chemical types include: anthrapyridone; anthraquinone; azo; nigrosine; perinone; pyrazolone; quinoline; quinophthalone; and xanthene.

Table 5 offers selection data to assist the colorist in making the initial selection when considering soluble dyes for a coloring of plastics project.

Table 6 offers usage information to act as an initial guide toward soluble dye selection.

7. Effect Colorants

Effect colorants cover a wide gamut of optical effects. They include, but are not limited to, metallic, pearlescent, fluorescent, phosphorescent, speckles, marble, granite, and others that will appear in the market place from time to time. There is such a wide variety in this group it is impossible to characterize them as done with the organic, inorganic pigment, and soluble dye groups.

Metallic pigments are normally thought of as aluminum flakes of various particle sizes. In fact, this is mainly true. The aluminum particles that are very small will exhibit a gray metallic sheen with no particular specular high lights. The larger sizes, sometimes called flake or dollars, can give attractive sparkling like effects. The addition of zinc and/or copper alloyed to the aluminum will exhibit brass, bronze, and copper appearing effects. A negative effect of these pigments is that they, as platelet shaped particles, will tend to align with polymer flow in injection molding and extrusion. This alignment with flow may show as undesirable visible flow lines in the product. The larger size particles tend to minimize this undesirable effect. Proper mold and die design can minimize and/or eliminate this appearance defect.

Table 4. **Typical Inorganic Pigment Applications**

	Thermoplastics[a]													Thermoset[a]					
	GPPS	LDPE	HDPE	PP	ABS	Acrylic	Acetal	Flex. PVC	Rigid PVC	Poly-amide	Cellu-lose	Poly-ester	Polycar-bonate	Flouro	Epoxy	Polyester	Phenolic	Silicone	Polyur-ethane
Violets																			
ultramarines	W	W	W	W	W	L	L	W	L	L	W	W	L	N	W	W	W	W	W
manganeses	W	W	W	W	L	L	N	W	W	N	L	W	N	N	W	W	L	L	W
complex inorganics	W	W	W	W	W	W	L	W	W	L	W	L	L	W	W	W	W	W	W
Blues																			
irons	L	W	L	L	N	N	N	L	L	N	L	L	N	N	L	L	L	L	L
ultramarines	W	W	W	W	W	W	W	W	W	W	W	W	W	N	N	W	W	W	W
manganeses	W	W	W	W	W	W	W	W	N	W	W	W	W	N	W	W	W	W	W
complex inorganics	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W
Greens																			
chromes	W	W	W	L	L	L	N	L	L	N	L	W	N	N	L	W	L	L	L
hydrated chomium oxides	W	W	W	W	L	L	N	W	L	N	L	L	N	N	W	W	L	W	W
chromium oxides	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	L	W	W
complex inorganics	W	W	W	W	W	W	L	W	W	W	W	W	W	W	W	W	W	W	W
Yellows																			
lead chromates	W	W	W	W	L	N	N	W	W	N	W	W	L	N	W	W	W	N	W
iron oxides	W	W	L	L	N	N	N	L	N	N	W	W	N	N	W	W	L	W	L
cadmiums	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	L	W
complex inorganics	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W
Oranges																			
lead molybdates	W	W	W	W	L	L	N	W	W	N	W	W	N	N	W	W	W	N	W
cadmiums	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W
iron oxides	W	W	L	L	N	N	N	W	L	N	W	W	N	N	W	W	L	N	L
Reds																			
ultramarines	W	W	W	W	W	L	L	W	W	L	W	L	L	N	W	W	W	L	W
cadmiums	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W
iron oxides	W	W	W	W	W	L	N	W	L	N	W	W	N	N	W	W	W	L	L

[a] W = widely used, L = limited use (testing suggested), N = not used.

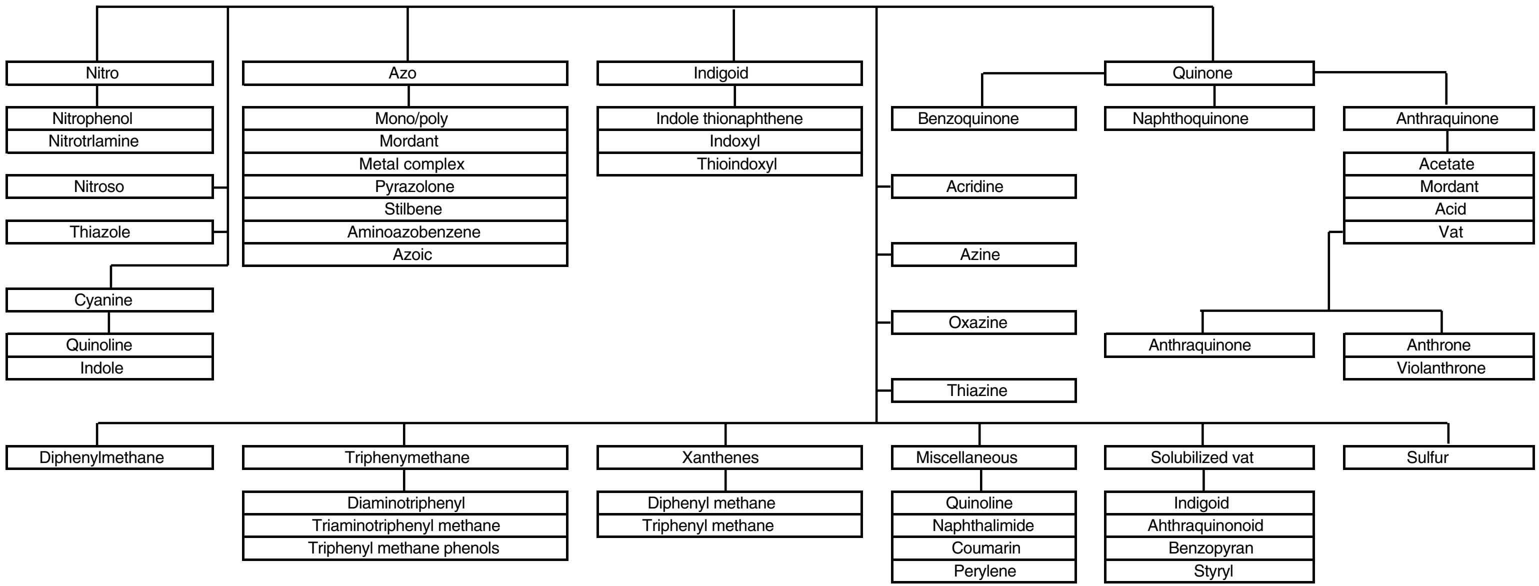

Fig. 5. Soluble dyes.

Table 5. **Selected Solvent Dyes for Plastics**

Colour Index name	Solvent dye chemical types	Colour Index number	CAS Registry number
Solvent Black 3	Disazo Black	26150	[4197-25-5]
Solvent Blue 35	Anthraquinone Blue	61554	[17354-14-2]
Solvent Blue 36	Anthraquinone Blue	61551	[14233-37-5]
Solvent Blue 58	Anthraquinone Blue	617043	[61814-09-3]
Solvent Blue 59	Anthraquinone Blue	61552	[6994-46-3]
Solvent Blue 70	Phthalocyanine Blue	N/A	[12237-24-0]
Solvent Blue 101	Anthraquinone Blue	615670	[6737-68-4]
Solvent Blue 102	Anthraquinone Blue	61501	[15403-56-2]
Solvent Blue 104	Anthraquinone Blue	61568	[116-75-6]
Solvent Blue 128	Anthraquinone Blue	N/A	[18038-99-8]
Solvent Green 3	Anthraquinone Green	61565	[128-80-3]
Solvent Green 5	Perylene Green (Yellow)	59075	[2744-50-5]
Solvent Green 28	Anthraquinone Green	625580	[71839-01-5]
Solvent Orange 7	Monoazo Orange	12140	[3118-97-6]
Solvent Orange 60	Perinone Orange	564100	[6925-69-5]
Solvent Orange 63	Thioxanthene Orange	68550	[16294-75-0]
Solvent Orange 107	Polymethine Orange	N/A	[185766-20-5]
Vat Red 1	Thioindigoid Red	73360	[2379-74-0]
Vat Red 41	Thioindigoid Red	73300	[522-75-8]
Solvent Red 23	Disazo Red	26100	[85-86-9]
Solvent Red 24	Disazo Red	26105	[85-83-6]
Solvent Red 26	Disazo Red	26120	[4477-79-6]
Solvent Red 1	Monoazo Red	12150	[1229-55-6]
Solvent Red 52	Anthrapyridone Red	68210	[81-39-0]
Solvent Red 111	Anthraquinone Red	60505	[82-38-2]
Solvent Red 135	Perinone Red	564120	[20749-68-2]
Solvent Red 149	Anthrapyridone Red	674700	[21295-57-8]
Solvent Red 155	Anthraquinone Red	N/A	[110616-99-4]
Solvent Red 168	Anthraquinone Red	60510	[1096-48-6]
Solvent Red 169	Anthraquinone Red	605060	[27354-18-3]
Solvent Red 172	Anthraquinone Red	607280	[68239-61-2]
Solvent Red 179	Perinone Red	564150	[6829-22-7]
Solvent Red 195	Monoazo Red	N/A	[164251-88-1]
Solvent Red 196	Benzopyran Red	505700	[52372-36-8]
Solvent Red 197	Benzopyran Red	505720	[52372-39-1]
Solvent Red 207	Anthraquinone Red	617001	[15958-68-6]
Solvent Red 242	Thioindigoid Red	73300	[522-75-8]
Vat Violet 1	Violanthrone Violet	60010	[1324-55-6]
Solvent Violet 11	Anthraquinone Violet	61100	[128-95-0]
Solvent Violet 13	Anthraquinone Violet	60725	[81-48-1]
Solvent Violet 14	Anthraquinone Violet	61705	[8005-40-1]
Solvent Violet 36	Anthraquinone Violet	N/A	[61951-89-1]
Solvent Violet 38	Anthraquinone Violet	615655	[63512-14-1]
Solvent Violet 59	Anthraquinone Violet	62025	[6408-72-6]
Solvent Yellow 14	Monoazo Yellow	12055	[842-07-9]
Solvent Yellow 16	Monoazo Yellow	12700	[4314-14-1]
Solvent Yellow 33	Quinoline Orange	47000	[8003-22-3]
Solvent Yellow 72	Azo Yellow	127450	[61813-98-7]
Solvent Yellow 93	Pyrazolone Yellow	48160	[4702-90-3]
Solvent Yellow 98	Thioxanthene Yellow	56238	[12671-74-8]
Solvent Yellow 114	Quinoline Yellow	47020	[7576-65-0]
Solvent Yellow 160	Coumarin Yellow	N/A	[35773-43-4]
Solvent Yellow 163	Anthraquinone Yellow	58840	[13676-91-0]

Table 5 (*Continued*)

Colour Index name	Solvent dye chemical types	Colour Index number	CAS Registry number
Solvent Yellow 176	Quinoline Red	47023	[10319-14-9]
Solvent Yellow 179	Styryl Yellow	N/A	[80748-21-6]
Solvent Yellow 185	Coumarin Yellow	551200	[27425-55-4]
Disperse Yellow 241	Pyridone Yellow	N/A	N/A

Aluminum-based pigments are not the only metallic pigments used in polymers. Appearance is the most visible, but not the only attribute of some specific metallics. An example might be stainless steel flakes or short wires. These materials, as an illustration, may bring corrosion resistance and/or electrical conductivity to a plastic product. Other metal-based materials are available for aesthetic as well as physical property enhancement.

Pearlescent (nacreous) pigments are sophisticated synthetic inorganic pigments. The original pearlescent pigments were made from materials extracted from fish scales. The physical and performance properties of these natural materials did not meet the demands of plastic processing and product life requirements. Most synthetic pearlescent pigments are mica-based flakes, however, new flake materials based on silicas and other inorganic materials are appearing in the market place. Depositing a very thin layer of titanium dioxide on very carefully selected and sized flakes produces the pearl effect. The observed pearl effect is a result of the interference, scatter, and transmission of white light. A similar effect pigment uses a very thin layer of iron oxide, titanium dioxide, and/or combinations of both producing varied color effects. Adjusting the thickness of the deposited layer provides selective color interference, scatter, and transmission resulting in colors ranging from metallic, red, blue, green, and copper colors.

Fluorescent and phosphorescent colorants fall into the luminescent colorant family. These colorants are soluble dyes or are soluble dyes converted into pigmentary forms. They are unique. They accept uv light reemitting that uv light as visible light is usually similar in hue to the spectral or diffuse pigment color observed. This results in colorants radiating visible light enhancing the base color. If viewed where no uv light is present, even the fluorescent or phosphorescent colorants appear dull and unattractive. The performance difference between fluorescent and phosphorescent colorants is time related. Fluorescent colorants radiate their visible light instantaneously. Phosphorescent colorants release their visible light energy over time resulting in a significant time delay before fading completely. These colorants are known more generally as "glow-in the-dark colorants".

Speckles and granite effects are created by a number of techniques. The speckle appearance is usually obtained by adding large size granular material of different colors during processing of the plastic into consumer products. Theses granular materials are, but not limited to, granulated colored thermoset plastics. Other particulate nonpolymeric materials may also be used. The main issues with these materials are that they must be compatible, remain

Table 6. **Typical Soluble Dye Applications**

	Thermoplastics[a]														Thermoset[a]				
	GPPS	LDPE	HDPE	PP	ABS	Acrylic	Acetal	Flex. PVC	Rigid PVC	Poly-amide	Cellu-lose	Poly-ester	Polycar-bonate	Fluoro	Epoxy	Polyester	Phenolic	Silicone	Polyur-ethane
Violets																			
anthraquinones	W	N	N	L	W	W	N	N	L	W	L	W	W	L	L	L	N	N	L
Blues																			
anthraquinones	W	N	N	L	W	W	N	N	L	W	L	W	W	L	L	L	N	N	L
Greens																			
anthraquinones	W	N	N	L	W	W	N	N	L	W	L	W	W	L	L	L	N	N	L
Yellows																			
anthraquinones	W	N	N	L	W	W	N	N	L	W	L	W	W	L	L	L	N	N	L
azos	W	N	N	L	N	W	N	N	N	N	L	W	W	N	N	N	N	N	N
methines	W	N	N	N	W	W	N	N	N	L	N	W	W	L	N	N	N	N	N
pyrazolones	W	N	N	N	W	W	N	N	N	N	N	W	W	N	N	N	N	N	N
pyridones	W	N	N	N	L	W	N	N	N	N	N	W	W	N	N	N	N	N	N
quinolines	W	N	N	N	W	W	N	N	N	N	L	W	W	N	N	N	N	N	N
quinophthalones	W	N	N	N	W	W	N	N	N	L	L	W	W	L	L	L	N	N	N
xanthenes	W	N	N	N	L	W	N	N	N	L	L	W	W	N	N	N	N	N	N
Oranges																			
azos	W	N	N	L	L	W	N	N	N	N	L	W	W	N	N	N	N	N	N
perinones	W	N	N	W	W	W	N	N	N	W	L	W	W	N	L	L	N	N	L
polymethines	W	N	N	W	W	W	N	N	N	N	L	W	W	N	N	N	N	N	N
thioxanthenes	W	N	N	L	L	W	N	N	N	N	N	W	W	N	N	N	N	N	N
Reds																			
anthraquinones	W	N	N	W	W	W	N	N	L	W	L	W	W	L	L	L	N	N	L
azos	W	N	N	L	L	W	N	N	N	N	L	W	W	N	N	N	N	N	N
benzopyrans	W	N	N	W	W	W	N	N	N	L	N	W	W	N	N	N	N	N	N
indigoids	W	N	N	L	L	W	N	N	N	N	N	W	W	N	N	N	N	N	N
perinones	W	N	N	W	W	W	N	N	N	W	L	W	W	N	L	L	N	N	L

[a] W = widely used, L = limited use (testing suggested), N = not used.

particulate, and not be soluble in the polymer system. Different effects are obtained through particle coloring, particle size, and particle size distribution.

Marble effects are produced differently in thermo and thermoset systems. A typical method for thermoplastics is to add pellets of the contrast or highlight color at the level needed for the desired effect. These pellets usually are a slightly incompatible polymer and/or have a slightly higher melting point. These characteristics retard or prevent homogenous mixing or dispersion of the highlight polymer during processing resulting in highlight streaks and swirls or a marbleized effect. In thermoset plastics, which are for the most part liquids, the highlight color liquid, which is identical or compatible with the base liquid, is carefully mixed into the system by various procedures that avoid complete mixing or dispersion. This leaves highlight color streaks and swirls that are ultimately cured with the base material. The result is the desired color effect contained in a completely cured homogeneous integral product.

Powdered thermoset systems such as melamines requiring a marble or other effects are usually made by imbedding a printed inlay into or under the surface of the product. The product then undergoes the cure process. The inlay highlight pattern is visible giving the effect and is protected by a layer of the cured thermoset polymer covering the inlay.

8. Special or Unusual Affect Colorants

These groups of colorants are difficult to classify. Some are pigments or distinctly different materials and others are soluble dyes. Every colorant brings an extraordinary visual effect not found in typical colorants.

Die cut or small strips of cellophane and/or mylar films exhibit striking visual effects. The thin films are vacuum metalized, color coated, or both. The die cut films can be any shape such as stars, rounds, squares, crescents, or any shape imaginable. The only criterion for use is that the die cut films meets all the specifications required for pigments and dyes.

Special light interference colorants take advantage of their ability to use light interference techniques to vary the perceived color depending on the viewing angle or conditions. Thus, as an example, at one viewing angle a product may appear green and as the viewing angle changes the color shifts to red. This dramatic change is known as “color travel”. These colorants have significant visual impact drawing attention to products. These special colorants, however, are very costly. Some of these special colorants are priced at hundreds of dollars per pound.

Chemiluminescent colorants are a group of chemicals that produce luminescence as a result of a chemical interaction with an oxidizer, usually a peroxide. An example would be the emergency chemical luminescent light sticks that produce a green fluorescence when the stick is bent releasing the oxidizer or the luminescent novelties found at carnivals. Other common colors produced by this system are yellow and red.

A natural luminescent light not normally thought of as a commercial product is bioluminescence. This is typically produced by luciferin in the bodies of

A. Industry is mature
B. Diketo-pyrrollo-pyrrole (DPP) new
C. Entirely new chromophores unlikely
D. Priority efforts to lower costs
E. Physical property focus?
  1. Dispersion improvements
  2. Physical properties
    Heat stability (incremental)
    Light stability (incremental)
    Weatherability (incremental)
    Strength (incremental)
  3. Focus on hue improvements
    Red
    Oranges
    Yellows
F. Market focus on (heavy) metal replacement
G. Tailoring colorants to meet application needs

Fig. 6. The future of organic pigments.

glowworms, fireflies, and some species of fungi. Plant genetics using gene transplants are a recent example.

Thermochromic colorants are prevalent in society today. These colorants, usually soluble dyes, are found in digital thermometer tapes and printings where the devices are used to detect whether frozen products have defrosted and spoiled or the opposite, where products if frozen become defective.

Photochromic colorants are soluble dyes that change hue when subjected to particular kinds of light. An example is the eyeglass lens that darkens when exposed to uv light in an outdoor situation.

Electroluminescent colorants are materials that emit visible light when an electrical charge or voltage is applied. The typical LED is an excellent example of this phenomenon.

There are others such as piezoluminescent and hydrochromatic materials that can produce strange color effects that do find small uses in commerce.

A. Industry is mature
B. Entirely new chromophores unlikely
C. Priority efforts to lower costs
D. Physical property focus?
  1. Properties
    Heat stability (incremental)
    Light stability (incremental)
    Weatherability (incremental)
    Strength (incremental, + 5−15%)
    Improved dispersion
  2. Focus on hue improvements
    Higher chroma
    Cleaner hues
    Larger color pallete
E. Market focus on nonheavy metal colorants
F. Tailoring colorants to meet application needs

Fig. 7. The future of inorganic pigments.

A. Industry is mature
B. Entirely new chromophores unlikely
C. Significant number of offshore manufacturers
   1. India
   2. Mainland China
   3. Minor domestic manufacture
D. Improvement focus?
   1. Properties
      Heat stability (little or none)
      Light stability (little or none)
      Weatherability (little or none)
      Improve chemical purity (substantial)
   2. Market focus
      Replace heavy metal colorants
      Supplement organic colorants to reduce cost
   3. Market and exploit color values
      Brightness
      Transparency
      Economics
   4. Focus on market growth

Fig. 8. The future of soluble dyes.

9. Future Considerations

The future considerations for organic and inorganic pigments and soluble dyes are outlined in Figures 6–8.

BIBLIOGRAPHY

"Colorants for Plastics" in *ECT* 3rd ed., Vol. 6, pp. 597–617, by T. G. Webber, Consultant, in *ECT* 4th ed., pp. 944–965, Gary Beebe, Rohm and Haas Company. "Colorants for Plastics" in *ECT* (online): posting date: December 4, 2000, by Gary Beebe, Rohm and Haas Company.

CITED PUBLICATIONS

1. T. B. Reeve and W. L. Dills, *Principles of Pigment Dispersion in Plastics*, 28th ANTEC Preprint, Society of Plastics Engineers, Inc. Brookfield, Conn. 1970, p. 574.
2. R. J. Kennedy and J. F. Murray, *Internal Pigmentation of Low Shrink Polyester Molding Compositions with Flushed Pigments*, 33rd ANTEC Preprint, Society of Plastics Engineers, Inc., Brookfield, Conn. 1975, p. 148.

GENERAL REFERENCES

Colour Index, and its Additions and Amendments, 3rd ed., Society of Dyers and Colourists, London, and American Association of Textile Chemists and Colorists, Durham, N.C.

Raw Materials Index, Pigments, National Paint & Coatings Association (NPCA), 1500 Rhode Island Avenue, N.W., Washington, D.C. 20005.

W. Herbst and K. Hunger, *Industrial Organic Pigments*, VCH Verlagsgesellschaft mbH, D-6940 Weinheim, Federal Republic of Germany, 1993.

G. Buxbaum, *Industrial Inorganic Pigments*, VCH Verlagsgesellschaft mbH, D-69451 Weinheim, Federal Republic of Germany, 1993.

T. C. Patton, *Pigment Handbook, Volume I*, John Wiley & Sons, Inc., New York, 1973.

Engelhard Corporation, private communication, 2003.

Polysolve, Inc., private communication, 2003.

Robert A. Charvat
Charvat and Associates, Inc.