TECHNICAL BULLETIN:
OPTICAL PROPERTIES OF POLYETHYLENE PRODUCTS

1. INTRODUCTION[1, 2]

Products quality is associated with their appearance and properties. Consumer performs the product quality perception. Often, appearance is the determining factor in purchasing decisions. Products with uneven or unacceptable appearance may lead to rejection by the purchaser.

In quality assurance programs the measurement of appearance is mainly used in manufactured products, for both commercial and industrial products. It is also applied in research and development of products to establish compliance with requirements previously established.

Object appearance consists of two main attributes: chromatic and geometric. Chromatic attributes are those associated directly with color, such as:

- **Hue**: perceived color of an object, for example red, yellow, green, blue or purple.
- **Purity**: deviation degree from gray color, also called saturation, chromaticity, vividness or brightness.

Geometric attributes, meanwhile, are those associated with light distribution on the object, including:

- **Brightness or gloss**: property associated with specular reflection. It is responsible for glossy or shiny appearance.
- **Haze**: is the light scattering inside or on a clear object surface which gives a hazy appearance. Presence of surface defects or particles inside a product can increase light scattering, which is generally perceived as haze or cloudiness.

A single change in geometric attributes (such as gloss) may cause an apparent change in color perception of an object, hence in its appearance.

2. OPTICAL PROPERTIES

2.1 Description

Properties that describe an object appearance are those known as optical properties: transparency, haze, gloss, and color.

An object's optical properties relate directly to light action, which may be reflected, absorbed and/or transmitted. Consequently, any change in part's thickness will affect the results of these properties measurements.

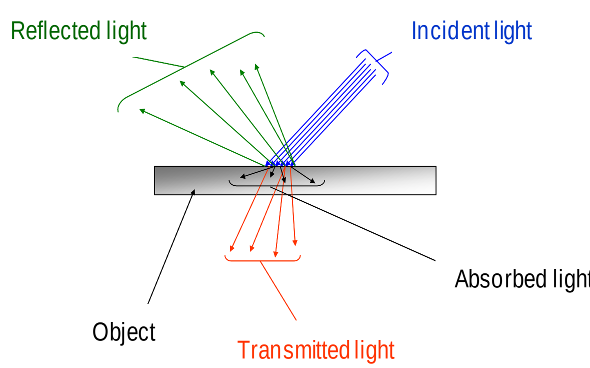

Figure 1. Light effect on objects.

When a light beam reaches an object means that:

- Brightness is proportional to the light reflected from the surface.

- Transparency is a combined effect, whose main component is the ability to transmit or not some of the incident light.
- Color and haze are different responses of the object in relation to absorb a portion of the light spectrum.

In glossy plastic parts, light is reflected in a single direction without dispersion (Figure 2).

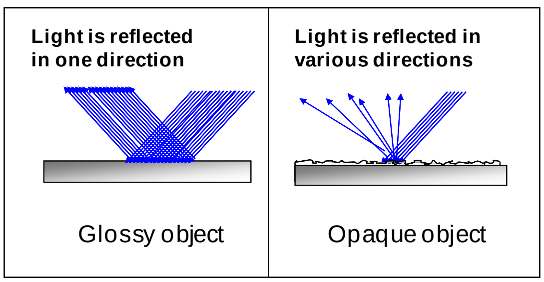

Figure 2. Brightness or gloss of an object

In transparent plastic parts, light should be able to be transmitted without dispersion (experimentally the limit is below ±2.5° from the incident angle).

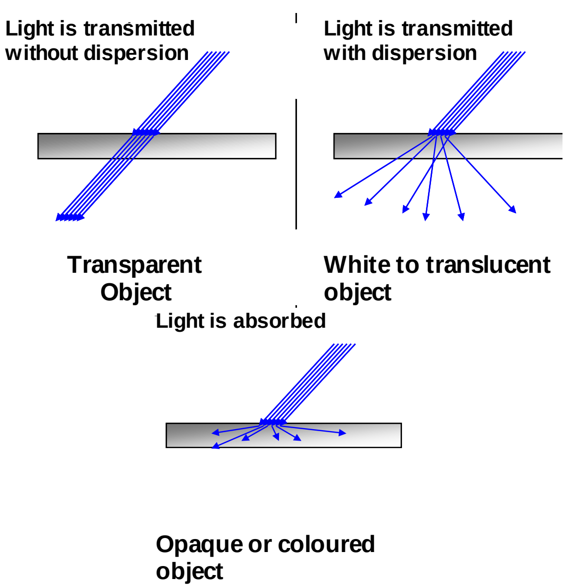

Figure 3. Effect of light on an object and its transparency

2.2 Measurement

2.2.1 Luminous Transmission and Haze

The measurement of luminous transmission and haze can be performed using the following international standards: ASTM D1003, ISO 13468-2 (luminous transmission) and ISO 14782 (haze). The test specimen **thickness must not exceed 10 mm.** Thicker specimens may be measured, but results may not be comparable.

2.2.2 Gloss

Gloss is a relative measurement compared to a calibrated standard (that is conveniently set at 100 units). Consequently, in a certain object, gloss can be greater than 100 units. Moreover, in perfect mirrors, results can reach values of 1000 and 2000 units (depending on the incidence angle of light).

Plastic films or solid parts gloss measurement, both opaque and transparent, may be performed under ASTM D2457 Standard, using a glossmeter. ISO has no specific standards for gloss measurement in plastics, but it does have for paper, board and pulps; also for paints and varnishes.

2.2.3 Color [1]

Color elements that determine its perception include (Figure 4):

1. Light source.
2. Type of object.
3. Observer´s eye/brain combination.

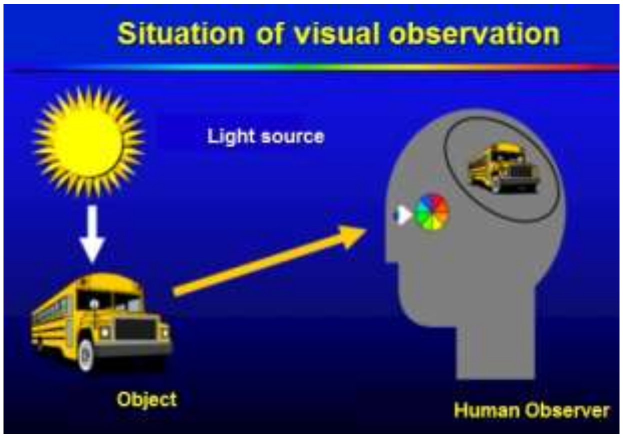

Figure 4. Visual observation.

Light from any source can be specified in accordance with the amount of light emitted, in wavelength, which is expressed in nanometers (nm).

For standardization purposes, the International Commission on Illumination, also known as CIE (by its French acronym: "Commission Internationale de l'Eclairage") established standards for light sources and illuminants.

Any source emits a real physical light that can be turned on and off. An **illuminant** (Figure 5) is defined by a specific spectral distribution, and it is possible or not to build a source that reproduces it.

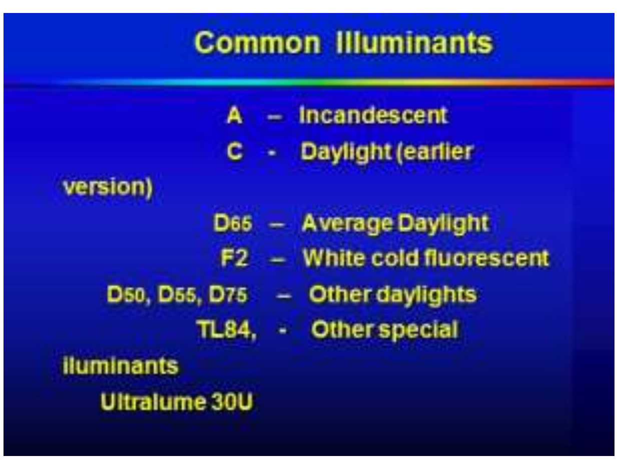

Figure 5. Common Illuminants

The most frequently illuminants used are identified by the letters A, C, D65 and F2. From these, the most widely used is D65, which represents average daylight.

Once the light source is quantified and standardized, it should be examined how light interacts with the second element: **the object.**

Objects modify reflected light. Dyes and pigments selectively absorb some wavelengths, while reflecting (or transmitting) others wavelengths.

The spectrophotometric curve does not depend on light source and observer judgment measurement, so that it becomes an intrinsic property of the object. In general, as a curve tends towards horizontality, the color is low in chromaticity or achromatic, like white, gray and black colors (Figure 6).

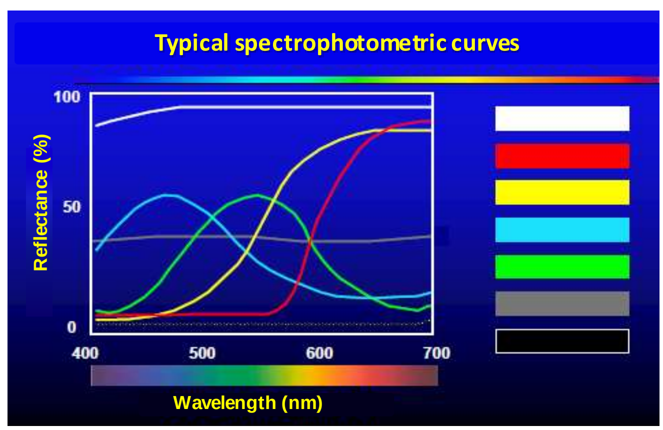

Figure 6. Typical spectrophotometric curves

Highly chromatic colors have curves with pronounced changes in direction, with a high reflectance in some regions and high absorption peaks in others.

The observer´s eye/brain combination is not as simple to quantify and measure as the other two elements. To measure this third element, light response receptors in human eye and its perception of luminance (gloss) must be considered. An analyst should measure human eye efficiency to convert different wavelengths in light intensity sensation**.**

Supported by the fact that red, green and blue lights, called spectral primary colors, may be combined to reproduce the full range of colors in the visible spectrum, it was concluded that there are sensitive receptors selective to red, green or blue lights in human eye. 1

Based on a series of experiments mixing colored lights, results were transformed in a mathematical expression that were adopted as the CIE response. In this scale, color is quantified using three axes X , Y and Z (one for each spectral primary color). This method is known as the CIE Standard Observer.

Another color scale for its quantification is the opponent-process theory of color from Adams and Hunter. This theory is known as the Lab Color Space with dimension ***L*** for lightness and ***a*** and ***b*** or CIELab for the color-opponent dimensions (Figure 7).

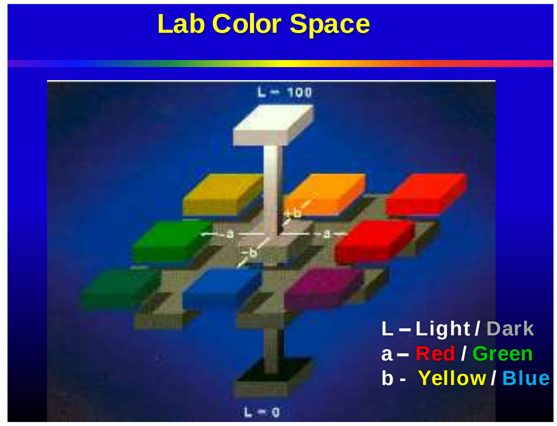

Figure 7. Hunter color scale.

This system of opponent color scale (Hunter scale) of three axis is based on the theory that color is perceived as a combination of black-white (**L**), red-green (**a**) and yellow-blue (**b**) sensations.

It is important to notice that color values are meaningless unless the following are identified:

- Scale used - CIELAB or Hunter
- Illuminant
- Observer
- Geometrical characteristics of the instrument used for measurement
- Specific procedure of measurement – i.e., number of readings, thickness, background, temperature, humidity, orientation.

For color measurement, a sample of material is placed in a tristimulus colorimeter type. The starting point is the calculation of the parameters X, Y and Z from a reference standard CIE system that allows to estimate yellowness index and whiteness, according to ASTM E313 Standard.

This practice should be used only to compare same material and same general appearance specimens. For example, a series of specimens (punched or cut) to be compared should have generally similar gloss, texture, and (if not opaque) thickness, and translucency.

3. EFFECT OF POLYMER INTRINSIC PROPERTIES[2]

Crystallization degree is the only fundamental property of polymers that has a significant effect on optical properties.

The presence of crystals generates light scattering, thus, the larger the amount and/or non-uniformity of their sizes, the lower the transparency of the polymer. Consequently, all amorphous polymers (polystyrene, acrylic, etc.) and all materials in molten state are transparent, since there are no crystals in them.

4. PROCESSING EFFECTS[3]

In rigid packaging, it is important to reduce the product cristalization. In injection or blow molding, lower crystallization is achieved with shorter cooling times.

In flexible packaging, where transparency requirements are very important, the optical properties are mainly affected by thickness and orientation of the film, as well as its surface defects.

Film thickness uniformity can be achieved by a good stabilization of the bubble and nip rollers rotation which define pulling speed in tubular film extrusion. A lower frost (freeze) line height (FLH) prevents molecular chains reorganization or orientation in extrusion direction (MD) and smaller crystals, which gives better optical properties: more transparency in the film.

In flat film process, a quenching step ensures the highest transparency for a particular material.

It must be recognized that changes in operation conditions made to modify optical properties will have an effect on other properties, such as mechanical properties.

5. CAUSES OF APPEARANCE PROBLEMS[1]

As mentioned earlier, film appearance for packaging is affected by the resin, equipment and processing conditions. Appearance problems are often associated with malfunction of these three components.

Despite supplier´s quality control, resin contamination is always a possibility that must be considered. There are other pollution sources located in different parts of the extruder, for example, dirty filters along production line. A nozzle, channel or any other flow area that it is not completely clean is able to produce gels as result, particularly when at a resin change is introduced. Such gels appear randomly throughout the product and may be transparent, black or amber.

Gels strongly affect flexible packaging and may appear as burned spots coming from stream-converging points in the die.

Other problem in flexible packaging appearance is the presence of lines along the bubble in transverse direction of extrusion (TD). This inconvenient can normally be eliminated by adjusting the volume of cooling air.

Streak defects in the film, occasionally intermittent and always parallel to extrusion direction (MD), can be produced by a sharp or abrasive surface of post-extrusion devices. This could be due to a stuck fragment on the surface of the collapsing frame or in dirty or contaminated stabilizations system, nip or chill rolls, etc.

The melt fracture phenomenon (orange peel, sharkskin) occurs when a critical shear stress on material is exceeded and may be present in any transformation process.

The secret of a well-colored product is to achieve an optimal pigment dispersion in the resin (physical mixing) and then, a good dispersive and distributive mixing given by the extruder screw. This involves uniform mixing of the resin with color concentrate (masterbatch) prior to extrusion.

For gloss improvement, being it a purely superficial property, relates to nozzle (die quality as well as processing conditions, mold cavities surfaces and material. In all cases, part's surface imperfections must be reduced, which may be caused by gels or defects in cavities or nozzles.

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In order to obtain more detailed information of the security aspects regarding the use and disposal of our products, we invite you to consult the material safety data sheets (MSDS) for Venelene® polyethylene.