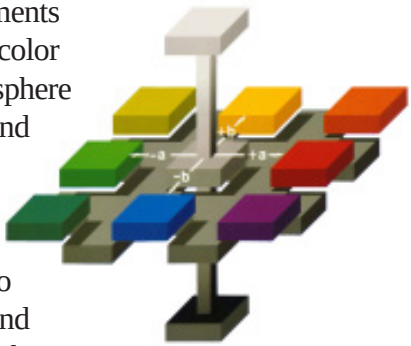
PET Bottle Manufacturing and Color Measurement

The plastic bottle industry has many producers, each striving to manufacture high quality products. Properties such as barrier characteristics, dimensional stability, shape and appearance are of significant importance. Appearance attributes can include reflected color, transmitted color, yellowness, and haze. For some applications the presence of proper levels of UV inhibitors is also important. The use of color measurement instrumentation to test and quantitate these attributes will ensure customer satisfaction and aid in reducing costs.

General Principles

There are two basic types of color measurement instruments, **tristimulus colorimeters** and **colorimetric spectrophotometers**. These instruments are categorized as psychophysical measurement instruments, meaning they are designed to give measurements that correlate with the human eye-brain impressions. They have built in characteristics that simulate the operation of the eye and brain in judgements of color appearance. The tristimulus colorimeter uses colored glass filters to simulate the human eye response to light and today finds limited application in the plastics industry. On the other hand, the more versatile colorimetric spectrophotometer is widely used in the plastics industry. It measures the wavelength distribution of light reflected or transmitted by a sample and this data is used to calculate color values. Instrument geometry generally falls into one of two categories: 45°/0°geometry or sphere (d/8°) geometry. For 45°/0° geometry instruments, the source light illuminates the sample at 45° and the light reflected at 0° (normal to the surface) is measured. The 45°/0°geometry instruments exclude the specular (gloss) component of reflected light meaning that the color they measure will be due to both sample pigmentation and sample surface characteristics. Frequently 45°/0°geometry instruments have measurement ports that are at least 2” in diameter giving a good optical average when measuring samples such as pellets. With sphere (d/8°) instruments the source light is projected into a sphere and is diffused by the sphere coating. This diffused light is incident on the sample and the light reflected at 8° is measured. Typically sphere instruments include the specular (gloss) component in the measurement meaning the color they measure will be due to sample pigmentation only. Instruments with sphere geometry normally have the added ability to measure transmitted color and haze in addition to reflected color.



Color is measured in terms of a tristimulus color scale such as the CIE L*a*b* scale. The L* value ranges from 0 to 100 and measures dark to light, the a* value measures red to green with positive values being red and negative values green. The b* value measures yellow to blue with yellow having positive values and blue negative values. Comparisons between a standard and a sample is expressed in terms of $\Delta L^*\Delta a^*\Delta b^*$. This is the difference in L*, a* and b* between the standard and the sample.

Using this information, one can interpret both the size of the difference (large or small numbers) and direction of color difference (+ or -). When determining acceptability, these numbers must fall within predetermined tolerance limits. In addition to tristimulus color scales there are single number indices for measuring whiteness and yellowness.

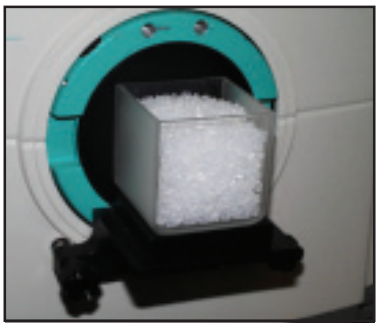
Sphere geometry spectrophotometers have proven to be the ideal tool for bottle makers to quantify appearance attributes. Users report that they find significant benefit in the spectrophotometer's ability to measure both reflectance and transmittance and to obtain both spectral data (to detect UV inhibitors) and tristimulus color data (for visual color), all with the same instrument. This type of instrument can be used to measure raw materials, preforms, bottles and closures during manufacture. It can also be used to measure fiber, film, sheet, and pellets for PET bottle recycling. Data can be displayed, printed, stored and/or exported to other programs. If desired, tolerances can be entered for Pass/Fail indication.

Pellets

The color, whiteness or yellowness of plastic pellets is often measured before the pellets are molded into preforms or final product. Plastic pellets have several non-uniform characteristics that require compensating preparation and presentation techniques in order to ensure repeatable sample measurement.

- They are in the form of a pellet – not a solid sample – and must be measured through the clear window of a glass cell in order to be effectively made into a "solid".
- Pellets are irregular in size and shape, requiring the averaging of several readings with refilling of the glass cell between each reading.
- Pellets are translucent – not opaque – and can be sensitive to ambient light and to small differences of the optical configuration of the instrument. Using sufficient sample thickness and an opaque cover will minimize these effects.

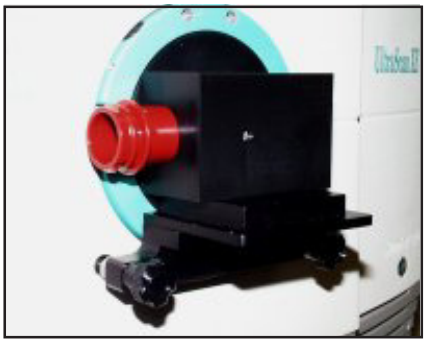
Both 45°/0°geometry and sphere (d/8°) geometry instruments can be used to measure plastic pellets. An instrument with 45°/0° geometry will normally give greater measurement precision when measuring pellets

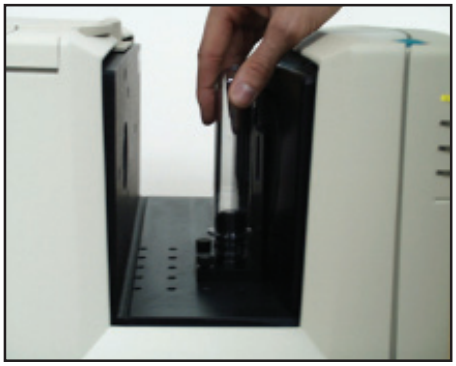


(due to this type of instrument's large measurement area) than sphere geometry instruments. However since sphere geometry instruments can be used for measurement at many other stages of the bottle making process, they are frequently used to measure pellets as well. In practice the pellets are poured into a large transmission type cell with 50mm path length. This large sample thickness makes the translucent, irregular pellets effectively opaque for reflectance measurement. The filled cell is placed on a sample shelf against the instrument reflectance port so that the pellets will be read through the clear glass window of the cell. A color reading of the pellets is then made. The pellets are then dumped out of the cell and poured back in and another reading made. This process is normally repeated three to five times and the readings averaged for a single color measurement. Averaging multiple readings minimizes measurement variation associated with non-uniform samples.

Preforms

The color of preforms is frequently measured prior to being reheat blow molded (RHB) into final bottle form. Ensuring that the preform color is correct greatly increases the probability that the blown bottle will have the proper color. Thus off-color bottles are reduced and money is saved. However, preforms can also be measured earlier in the process. Measuring the preform during the product change-over process helps to get the process on color more quickly saving time and money. Transparent preforms are measured by transmission and near opaque or opaque preforms are measured by reflection. Because of their cylindrical shape, preforms require special sample-handling to precisely position the sample to be measured. This is accomplished by use of "Preform Holders". For transmission, a holder having an aperture and an insert that is the proper size for the preform being measured, are mounted in the instrument transmission compartment. The instrument is standardized for total transmission and small area view. The preform is placed on the preform insert and a reading taken. The preform is then rotated and another reading made. After a few readings are taken the average is recorded as the measurement. For "colorless" preforms it may be desirable to measure yellowness and for some applications confirm that the proper levels of UV inhibitors are present. Yellowness is measured as a single number scale that is calculated and displayed by the instrument's software. For UV inhibitors the spectral data between 360nm to 420nm is viewed. Low transmittance values in this range indicate the presence of UV inhibitors. Higher transmittance values indicate less or no inhibitor.





For reflection measurement, a modified sample shelf is mounted at the reflectance measurement port of the instrument. After the instrument is standardized for small area reflectance a preform holder attachment having the proper diameter for the preform to be measured is snapped onto the sample shelf. The preform is then inserted and measurements made much like those for transmission.

Bottles

The color of bottles can also be measured. For opaque or near opaque bottles, reflected color is measured. Although a whole bottle can be measured by placing a relatively flat and smooth surface of the bottle against the instrument's reflectance port, greater precision will be achieved by cutting a section from the bottle. The cut section is pressed flat against the instrument's measurement port. For transparent bottles a positioning device is mounted in the instrument transmission compartment. This device is used to reproducibly position the bottle. The bottle should be filled with distilled water to reduce the reflection from interior bottle surfaces. This simulates the optical conditions of the bottle in use. If a smooth section can be cut from a bottle for measurement, greater precision will be achieved and if desired, transmission haze of the bottle material can also be measured. Haze is the scattering of light within a nearly clear specimen and is

responsible for cloudy appearance. The cut section to be measured is held in place against the sphere on the inside of the instrument transmission compartment by a “Transmission Sample Clamp”.

Caps

The color of bottle closures can be measured. In most cases the small area reflectance mode of the instrument is used and a relatively flat surface, such as the top of the closure, is placed against the instrument port. If the top is not flat, then the side of the closure is measured. A positioning fixture mounted at the reflectance port would be used to ensure that the closures are reproducibly positioned.

Collected PET bottles are frequently recycled into fiber, film, sheet, pellets and new bottles. Fiber color, whiteness or yellowness can be measured by using a “Compression Cell Attachment” on the instrument. This device is used for compressing fibers into a compact mass to permit repeatable color analysis. A specified amount of fiber is placed in a container having a glass window in the bottom and air pressure is applied to a piston to compress the fiber. By applying a consistent amount of pressure to the piston and using a consistent amount of fiber, a consistent yarn density is achieved for reproducible measurements. Recycled film and sheet would be measured similar to methods used for measuring bottles.

The colorimetric spectrophotometer is a useful tool for measuring color at many phases of the bottle making process. Checking the color of raw material such as pigment, resin and compound helps to ensure that the molded preform will be the proper color. And checking preform color ensures that the blown bottle will meet color requirements. This enables the bottle manufacturer to produce the highest volume of quality product at the lowest cost.