



# Enhancing Transparent and Translucent Plastic Preform Manufacturing through Spectrophotometric Color Quality Control

## Introduction

Plastic preforms—also called parisons or bottle blanks—are the foundation of modern PET beverage packaging. These injection-molded components ultimately become the bottles consumers see on store shelves, making preform quality a critical factor in final package appearance and customer acceptance.

Among the various quality attributes that influence bottle appearance, color is one of the most important indicators of preform quality and process consistency. Subtle shifts in color can reveal changes in raw materials, additive concentrations, oxygen scavenger loading, processing conditions, or thermal degradation long before those changes become visible in finished bottles. Because preforms are produced before the blow-molding process, color measurement provides manufacturers with an early opportunity to identify and correct process variation before significant downstream costs are incurred.

While bottle clarity is also an important quality attribute, haze measurements are typically performed on finished blown bottles rather than directly on preforms. The geometry and wall thickness variations inherent to preforms make them unsuitable for accurate haze measurement. Instead, haze is most accurately evaluated using representative bottle-wall cutouts measured according to established haze measurement methods such as ASTM D1003.

This white paper explores how spectrophotometric color measurement can be used to improve quality control for transparent PET preforms and how bottle haze measurements can complement a comprehensive packaging quality program. The discussion focuses on the role of color measurement in detecting process variation, monitoring oxygen scavenger loading, controlling yellowness, and maintaining bottle-to-bottle consistency.

The paper also reviews industry standards, best practices, and practical implementation strategies for integrating objective color measurement into the manufacturing process. HunterLab's Vista® L2 spectrophotometer is presented as a



recommended solution for transmission color measurement of transparent preforms, while haze measurement methodologies for finished bottle cutouts are discussed as part of a complete quality assurance program.

By aligning these recommendations with real-world manufacturing requirements and recognized industry standards, manufacturers can improve process control, reduce waste, enhance product consistency, and strengthen customer confidence in package appearance.

## Overview

To appreciate the importance of color measurement, it is helpful to understand the role preforms play within the packaging supply chain.

PET preforms represent one of the largest segments of the global plastics packaging industry. Billions of preforms are manufactured annually for bottled water, carbonated soft drinks, juices, teas, sports drinks, edible oils, personal care products, household chemicals, and numerous other applications. Regardless of the final package design, every transparent PET bottle begins as a preform.

The appearance of the final bottle is heavily influenced by the quality of the preform. Variations in color introduced during resin production, additive dosing, drying, injection molding, or material handling often become amplified in the finished package. As a result, many manufacturers utilize color measurement at the preform stage as an early process-control checkpoint.

Objective color measurement allows manufacturers to:

- Monitor process consistency.
- Verify additive loading.
- Control yellowness and color drift.
- Detect thermal degradation.
- Evaluate oxygen scavenger concentration.
- Support supplier quality programs.
- Improve bottle-to-bottle consistency.



Because color can be measured directly on the preform, manufacturers gain rapid feedback without the need to first produce bottles. This allows quality issues to be identified and corrected earlier in the production process.

For bottle clarity evaluation, however, the recommended approach differs. Haze measurements are typically performed on representative bottle-wall cutouts produced from blown bottles. This provides a flat, uniform specimen suitable for ASTM D1003 haze measurement and eliminates optical distortion associated with curved preform geometry.

Together, preform color measurement and bottle haze evaluation provide manufacturers with a comprehensive approach to controlling package appearance and maintaining consistent product quality.

## Understanding PET Preforms

PET (Polyethylene Terephthalate) preforms are injection-molded intermediates used to manufacture transparent plastic bottles and containers. Often referred to as "test tubes with threads," preforms contain all the material necessary to produce the final package and serve as the starting point for the blow-molding process.

During bottle production, preforms are reheated and stretched into their final shape using blow-molding equipment. While the shape of the package changes dramatically during this process, many of the optical characteristics present in the preform ultimately influence the appearance of the finished bottle. As a result, the preform stage provides an ideal opportunity to evaluate material quality and process consistency before additional value is added through bottle production, filling, labeling, and distribution.

## Why Preforms Are Used for Quality Control

Preforms are often easier and less expensive to inspect than finished bottles. They require less storage space, are easier to transport, and can be evaluated immediately after injection molding without waiting for downstream bottle production.

For this reason, many manufacturers utilize preforms as an early process-control checkpoint to monitor:

- Color consistency



- Resin quality
- Additive loading
- Oxygen scavenger concentration
- Thermal degradation
- Process stability
- Supplier-to-supplier variation

Identifying variation at the preform stage allows manufacturers to correct problems before large quantities of bottles are produced, reducing scrap, rework, and production downtime.

### **What Influences Preform Color?**

Although PET is generally considered a transparent material, many factors can influence its color and appearance.

#### **Resin Variation**

Differences in resin production, raw material sourcing, and manufacturing conditions can produce measurable color variation between resin lots. Even small shifts may become visible when large quantities of bottles are displayed side-by-side on store shelves.

#### **Processing Conditions**

Injection molding conditions can significantly affect preform color.

Examples include:

- Excessive residence time
- High melt temperatures
- Improper drying
- Moisture contamination
- Thermal degradation

These conditions can produce subtle shifts in color that may indicate underlying process issues before they become larger quality problems.



## Additives and Modifiers

Modern PET packaging frequently incorporates additives designed to improve product performance.

Examples include:

- Oxygen scavengers
- UV absorbers
- Acetaldehyde scavengers
- Colorants
- Reheat additives

Many of these additives influence optical properties and can produce measurable changes in color values.

## Recycled Content

As sustainability initiatives continue to drive increased recycled content usage, manufacturers often encounter greater variability in material appearance.

Changes in recycled feedstock quality, processing history, and contaminant levels may influence color consistency and increase the importance of routine color monitoring.

## Color as an Early Indicator of Process Health

One of the most important benefits of spectrophotometric color measurement is its ability to function as an early warning system.

A change in color does not necessarily represent a customer-visible defect. In many cases, it serves as an indication that something within the process has changed.

Examples include:

- Resin lot changes
- Dryer performance issues
- Processing temperature shifts
- Additive dosing variations
- Equipment maintenance concerns



By monitoring color consistently, manufacturers can often identify these changes before they affect finished bottle quality.

### **Oxygen Scavenger Systems and L\***

Many beverage packaging applications utilize oxygen scavenger technologies to extend product shelf life and protect flavor stability.

Oxygen scavengers are commonly used in:

- Juices
- Teas
- Sports drinks
- Functional beverages
- Sensitive food products

As oxygen scavenger concentration increases, the preform typically becomes darker, resulting in a measurable decrease in L\* values.

Because of this relationship, many manufacturers utilize L\* as a process-control parameter to verify oxygen scavenger loading consistency between production lots.

Monitoring L\* allows manufacturers to:

- Verify additive loading.
- Detect dosing variation.
- Improve lot-to-lot consistency.
- Support process validation activities.

Color measurement therefore becomes more than a cosmetic evaluation—it becomes a practical manufacturing control tool.

### **Preforms Versus Finished Bottles**

While preforms are excellent samples for color measurement, they are not ideal samples for every optical property.

The geometry of a preform includes:

- Curved surfaces



- Variable wall thickness
- Gate structures
- Neck finishes

These features can influence the transmission of light and complicate certain optical measurements.

As a result, manufacturers typically use:

- **Preforms for color measurement**
- **Bottle cutouts for haze measurement**

This distinction is important because it allows each property to be measured using the most appropriate sample geometry and testing method.

### **Key Takeaway**

PET preforms serve as an important process-control checkpoint within bottle manufacturing operations. By monitoring color at the preform stage, manufacturers can detect resin variation, additive loading changes, thermal degradation, and process instability before these issues affect finished bottles. Objective color measurement provides valuable insight into manufacturing performance and helps establish a foundation for consistent bottle quality.

## **Why Measure Color on Preforms?**

Color is one of the earliest and most sensitive indicators of process consistency within PET packaging manufacturing. While consumers ultimately evaluate the appearance of the finished bottle, measuring color at the preform stage allows manufacturers to identify variation much earlier in the production process—before additional value has been added through blow molding, filling, labeling, packaging, and distribution.

For many manufacturers, color measurement is not simply a quality inspection activity; it is a process-control tool that provides insight into material consistency, manufacturing performance, and product quality.

### **Detecting Variation Before It Becomes Expensive**

One of the greatest advantages of measuring color on preforms is the ability to detect process changes before they result in large quantities of nonconforming bottles.



A shift in color may indicate:

- A change in resin properties.
- Variation in additive concentration.
- Dryer performance issues.
- Processing temperature changes.
- Material contamination.
- Thermal degradation.
- Equipment performance issues.

When these changes are identified at the preform stage, corrective action can often be taken before significant downstream costs occur.

The earlier a problem is identified, the lower the cost of correction.

### **Monitoring Process Stability**

Consistent color measurements are often an indicator of a stable manufacturing process.

When color measurements remain within established limits, manufacturers gain confidence that:

- Raw materials remain consistent.
- Additive systems are functioning correctly.
- Processing conditions remain stable.
- Production equipment is operating as expected.

Conversely, unexpected color shifts may indicate that a process parameter has changed and requires investigation.

Many facilities routinely trend color data over time to identify gradual process drift before it becomes a quality issue.

### **Controlling Yellowness**

One of the most common appearance concerns in PET packaging is yellowing.



Yellowing may result from:

- Excessive heat exposure.
- Thermal degradation.
- Improper drying.
- Material aging.
- Processing instability.

These changes are often reflected in:

- $b^*$  values.
- Yellowness Index measurements.
- Whiteness Index measurements.

Monitoring these values allows manufacturers to identify developing trends and maintain tighter control over package appearance.

### Verifying Oxygen Scavenger Loading

For oxygen-sensitive products, oxygen scavenger systems play an important role in extending shelf life and protecting product quality.

Because oxygen scavengers typically darken the preform as concentration increases, manufacturers often monitor  $L^*$  values as a verification tool.

Consistent  $L^*$  measurements can help confirm:

- Proper additive dosing.
- Lot-to-lot consistency.
- Process repeatability.
- Material conformity.

In many applications,  $L^*$  becomes an indirect indicator of oxygen scavenger concentration and process performance.

### Supporting Supplier Quality Programs



Many bottle manufacturers receive preforms, resin, additives, or other materials from multiple suppliers.

Objective color measurement provides a common language for evaluating material consistency and communicating quality expectations throughout the supply chain.

Color specifications can be used to:

- Qualify suppliers.
- Verify incoming materials.
- Monitor lot-to-lot consistency.
- Investigate customer complaints.
- Support corrective actions.

By replacing subjective visual evaluations with objective measurements, organizations can improve consistency and reduce disagreement between suppliers and customers.

### **Correlating to Finished Bottle Appearance**

Although color is measured on the preform, the ultimate goal is controlling the appearance of the finished bottle.

Many manufacturers establish correlations between:

- Preform color.
- Finished bottle color.
- Customer appearance requirements.

This allows color measurements collected during preform production to serve as an early predictor of finished bottle quality.

Rather than waiting until bottles are produced, manufacturers can make process decisions based on objective data collected earlier in the manufacturing process.

### **Why Visual Inspection Alone Is Not Enough**

Historically, many facilities relied on visual inspection to evaluate preform appearance.

While visual inspection remains important, it has several limitations:

- Subjective interpretation.



- Observer-to-observer variation.
- Lighting differences.
- Fatigue effects.
- Inconsistent evaluation criteria.

Spectrophotometers eliminate much of this variability by providing objective numerical measurements that can be trended, analyzed, and communicated consistently across facilities and organizations.

This allows manufacturers to establish measurable quality standards rather than relying solely on human perception.

### **Business Benefits of Measuring Color on Preforms**

Implementing objective color measurement can provide significant operational benefits, including:

- Reduced scrap.
- Reduced rework.
- Improved process consistency.
- Faster troubleshooting.
- Improved supplier quality management.
- Reduced customer complaints.
- Improved production efficiency.
- Better product appearance consistency.

Because preforms represent an early stage in the manufacturing process, improvements achieved at this point often generate benefits throughout the remainder of the production chain.

### **Key Takeaway**

Color measurement at the preform stage provides manufacturers with an early, objective indicator of material quality and process stability. By monitoring color, yellowness, and L\* trends, manufacturers can identify variation before it affects



finished bottles, improve process control, reduce quality costs, and maintain consistent package appearance.

## What Can Color Reveal About Preform Quality?

Color is more than a visual attribute—it is often a direct reflection of material quality, processing conditions, additive performance, and overall manufacturing consistency. Because color is highly sensitive to even small changes in the production process, spectrophotometric measurements can provide valuable insight into what is happening inside the manufacturing operation long before a problem becomes visible to customers.

For many manufacturers, color measurement serves as both a quality control tool and a process diagnostic tool.

### Resin Quality and Consistency

One of the most common sources of color variation is the resin itself.

Even when resin suppliers meet all published specifications, small differences between lots can produce measurable changes in color. These differences may result from:

- Raw material sourcing.
- Polymerization conditions.
- Additive packages.
- Production methods.
- Storage conditions.

Routine color measurement helps manufacturers verify incoming material consistency and identify resin-related variation before it affects production.

In many facilities, color data is routinely reviewed alongside supplier certificates of analysis to provide an additional level of quality verification.

### Thermal Degradation

PET is sensitive to excessive heat exposure during processing.



When processing temperatures become too high or residence times become excessive, thermal degradation can occur. This degradation often manifests as a change in color before other material properties are affected.

Common indicators include:

- Increased yellowness.
- Darkening of the material.
- Reduced L\* values.
- Increased b\* values.

Color measurement can therefore serve as an early indicator that processing conditions may require adjustment.

### **Common Causes of Thermal Degradation**

- Excessive barrel temperatures.
- Long residence times.
- Production interruptions.
- Improper startup procedures.
- Reprocessing of degraded material.

By identifying color changes early, manufacturers can often correct processing issues before significant quantities of material are affected.

### **Moisture and Drying Performance**

PET must be properly dried before processing.

Excess moisture can contribute to hydrolytic degradation, which may affect both material performance and appearance.

Symptoms may include:

- Increased yellowness.
- Color drift.
- Reduced clarity.



- Reduced molecular weight.

Because color often changes before more serious defects become apparent, routine color monitoring can help identify dryer performance issues and moisture-related problems early in the process.

### Oxygen Scavenger Loading

Many beverage packaging applications utilize oxygen scavenger technologies to protect sensitive products from oxygen exposure.

Common applications include:

- Juices.
- Teas.
- Sports drinks.
- Nutritional beverages.
- Functional beverages.

As oxygen scavenger concentration increases, preforms often become darker.

This change is typically observed as:

- Reduced  $L^*$  values.
- Increased grayness.
- Slight shifts in overall appearance.

Because of this relationship, many manufacturers use  $L^*$  measurements as a process-control parameter to verify oxygen scavenger loading consistency.

Monitoring  $L^*$  trends can help identify:

- Additive dosing variation.
- Process drift.
- Material inconsistencies.
- Equipment performance issues.



In many operations, color measurement provides a fast, non-destructive method for verifying oxygen scavenger performance without interrupting production.

### **Additive and Colorant Variation**

Many PET packaging systems incorporate additives designed to improve performance or appearance.

Examples include:

- Oxygen scavengers.
- UV absorbers.
- Acetaldehyde scavengers.
- Colorants.
- Toners.
- Processing aids.

Changes in additive concentration can often produce measurable color shifts.

For example:

- Excess blue toner may produce a bluish appearance.
- Insufficient toner may allow yellow tones to become visible.
- Inconsistent additive feeding may create lot-to-lot variation.

Color measurements provide an objective method for monitoring additive consistency and verifying formulation performance.

### **Process Stability**

Consistent color measurements are often a sign of a stable manufacturing process.

When color remains within established limits, manufacturers gain confidence that:

- Material inputs remain consistent.
- Processing conditions remain stable.
- Equipment is operating correctly.
- Product quality is under control.



Conversely, unexpected shifts in color frequently indicate that something within the process has changed.

This is one reason why many facilities trend color measurements over time rather than evaluating only pass/fail results.

Trend analysis can reveal:

- Gradual process drift.
- Seasonal variation.
- Equipment wear.
- Raw material changes.
- Emerging quality issues.

### **Customer and Brand Requirements**

Many beverage companies maintain strict appearance specifications for packaging materials.

Even small color variations may be unacceptable because they can affect:

- Brand consistency.
- Shelf appearance.
- Consumer perception.
- Product differentiation.

Objective color measurement allows manufacturers to quantify appearance rather than relying solely on subjective visual inspection.

This provides a common language for communication between:

- Resin suppliers.
- Preform manufacturers.
- Bottle producers.
- Brand owners.
- Quality teams.



## A Practical Example

Consider a beverage packaging manufacturer producing preforms for a premium bottled water brand.

Routine color measurements begin to show a gradual increase in  $b^*$  values over several production lots.

Although the change is not yet visible to operators, the trend indicates increasing yellowness.

Further investigation identifies:

- Reduced dryer performance.
- Elevated resin moisture levels.
- Early-stage thermal degradation.

The issue is corrected before bottles are produced, preventing a potentially costly quality event.

Without objective color measurement, the problem might not have been detected until finished bottles reached customers.

## Key Takeaway

Color measurements provide valuable insight into material quality, additive performance, oxygen scavenger loading, processing conditions, and overall manufacturing stability. Because color often changes before other defects become visible, spectrophotometric measurement serves as an effective early warning system that helps manufacturers identify problems sooner, improve process control, and maintain consistent package appearance.

## Why Haze Should Be Measured on Bottles, Not Preforms

While color measurement is ideally suited for PET preforms, haze measurement presents a different challenge. Although haze is an important appearance attribute for transparent packaging, the geometry of a preform makes it unsuitable for accurate haze evaluation.

For this reason, industry best practice is to measure color on the preform and measure haze on a representative bottle-wall cutout after the bottle has been blown.



This approach provides more meaningful data, better correlation to consumer perception, and improved compliance with established haze measurement methods.

### **What Is Haze?**

Haze is a measure of light scattering within a transparent material.

As light passes through a plastic sample, some of the light travels directly through the material while some is scattered by:

- Crystalline structures.
- Contaminants.
- Additives.
- Voids.
- Surface imperfections.
- Material inhomogeneities.

The greater the amount of scattered light, the higher the haze value.

As haze increases, transparency decreases and the material appears:

- Cloudy.
- Milky.
- Frosted.
- Less clear.

For packaging applications such as bottled water and premium beverages, low haze is often an important quality requirement because consumers associate clarity with purity and quality.

### **Why Preforms Are Difficult to Measure for Haze**

Unlike flat plastic films or plaques, preforms contain complex geometries that influence the path of light through the material.

Examples include:

- Curved surfaces.



- Varying wall thickness.
- Neck finishes.
- Gate structures.
- Rounded cross-sections.

These features create optical distortion that can significantly influence haze measurements.

As light passes through a curved preform, refraction and lensing effects can occur, causing the measured result to reflect the sample geometry rather than the material itself.

As a result, two identical materials may produce different haze values simply because of differences in measurement location or orientation.

This makes accurate and repeatable haze measurement on preforms difficult.

### **Why Bottle Cutouts Provide Better Results**

After blow molding, bottles contain large flat or nearly flat sidewall sections that are much better suited for optical measurement.

A bottle-wall cutout provides:

- Consistent thickness.
- Reduced optical distortion.
- Improved repeatability.
- Better compliance with haze measurement methods.
- Better correlation to actual package appearance.

Because consumers ultimately evaluate the appearance of the bottle rather than the preform, bottle cutouts also provide a more representative assessment of final product quality.

For these reasons, bottle cutouts are the preferred sample for haze evaluation.

### **Recommended Haze Measurement Method**

The recommended procedure is:



1. Blow a representative bottle using normal production conditions.
2. Cut a flat section from the bottle sidewall.
3. Avoid highly curved regions, neck finishes, and molded features.
4. Measure haze and total transmittance using an appropriate haze measurement method.
5. Compare results against established specifications and historical performance data.

This approach minimizes measurement variability while providing meaningful information about bottle clarity.

### **ASTM D1003 and Bottle Haze Measurement**

The most widely recognized haze measurement standard for transparent plastics is ASTM D1003.

ASTM D1003 defines methods for measuring:

- Total luminous transmittance.
- Haze.

The method was developed around flat transparent specimens where transmitted and scattered light can be accurately measured.

Because bottle-wall cutouts provide a flat sample geometry, they are much better aligned with the intent of ASTM D1003 than intact preforms.

By utilizing bottle cutouts, manufacturers can improve measurement consistency and achieve better correlation between instrumental results and visual appearance.

### **What Haze Can Reveal About Bottle Quality**

Bottle haze measurements can provide insight into:

#### **Material Quality**

Higher haze values may indicate:

- Resin contamination.
- Recycled material variation.



- Additive incompatibility.
- Material degradation.

### **Processing Conditions**

Changes in haze may indicate:

- Improper drying.
- Thermal degradation.
- Crystallization.
- Blow-molding process variation.

### **Package Appearance**

Perhaps most importantly, haze measurements provide an objective method for evaluating bottle clarity and consumer-visible appearance.

Because clarity is often a critical quality attribute, haze measurements help ensure bottles consistently meet customer expectations.

### **Color and Haze: Complementary Measurements**

Color and haze measurements should not be viewed as competing tests.

Instead, they provide different information at different stages of production.

### **Preform Color Measurement**

Used to evaluate:

- Resin consistency.
- Additive loading.
- Oxygen scavenger concentration.
- Process stability.
- Color specifications.

### **Bottle Haze Measurement**

Used to evaluate:



- Package clarity.
- Light scattering.
- Transparency.
- Final bottle appearance.
- Customer acceptance criteria.

Together, these measurements provide a comprehensive approach to packaging quality control.

### **Key Takeaway**

Color and haze are both important appearance attributes, but they are best measured using different sample types. Preforms provide an excellent sample for color measurement and process control, while bottle-wall cutouts provide a more accurate and representative sample for haze evaluation. By measuring color on preforms and haze on finished bottle cutouts, manufacturers can improve measurement accuracy, strengthen quality control programs, and better predict final package appearance.

## **Implementing Color Measurement in Preform Manufacturing**

Understanding the value of color measurement is only the first step. To achieve meaningful results, manufacturers must implement a measurement program that produces accurate, repeatable, and actionable data.

Successful color quality control programs combine appropriate instrumentation, consistent measurement procedures, representative sampling, and clearly defined acceptance criteria. When these elements work together, color measurement becomes a powerful process-control tool rather than simply a pass/fail inspection activity.

### **Establishing Measurement Standards**

Every color measurement program begins with a standard.

A standard represents the approved appearance of the product and serves as the reference against which future production is evaluated.



Standards may be established using:

- Approved production preforms.
- Customer-approved samples.
- Master production standards.
- Digital color standards.
- Physical reference standards.

Regardless of the approach used, the standard should represent the appearance that the organization intends to reproduce consistently over time.

Once established, all future measurements can be compared to this reference to determine whether production remains within acceptable limits.

### **Defining Color Tolerances**

A standard by itself does not define acceptable variation.

Manufacturers must also establish color tolerances that define how much variation is acceptable before corrective action is required.

Color tolerances are commonly expressed using:

- $\Delta E$
- $\Delta E$  CMC
- $\Delta E_{2000}$

The appropriate tolerance depends on:

- Customer requirements.
- Product application.
- Visual sensitivity.
- Manufacturing capability.

For example, a premium bottled water application may require tighter tolerances than an industrial packaging application because consumers are highly sensitive to appearance differences in transparent packaging.



Well-defined tolerances allow operators to make consistent decisions and reduce subjective interpretation.

### **Selecting Representative Samples**

One of the most important aspects of any measurement program is selecting representative samples.

The objective is not simply to measure a single preform, but to understand the overall condition of the production process.

Sampling plans may vary depending on:

- Production volume.
- Customer requirements.
- Process capability.
- Historical performance.

Many facilities measure multiple preforms from each production lot and use average values to evaluate process performance.

This approach reduces the influence of isolated variation and provides a more representative assessment of production quality.

### **Standardizing Sample Presentation**

Consistent sample presentation is essential for obtaining repeatable measurements.

Variability in sample positioning can introduce unnecessary measurement variation that may be incorrectly interpreted as process variation.

Best practices include:

- Using dedicated preform fixtures.
- Measuring at a consistent location.
- Maintaining consistent sample orientation.
- Following documented measurement procedures.
- Training operators on proper measurement techniques.



By standardizing the measurement process, organizations can improve repeatability and confidence in the resulting data.

### Trending Data Over Time

One of the greatest advantages of spectrophotometric measurement is the ability to trend data over time.

Rather than evaluating only whether a sample passes or fails specification, manufacturers can monitor long-term trends in:

- $L^*$
- $a^*$
- $b^*$
- Yellowness Index
- Whiteness Index
- $\Delta E$

Trend analysis often reveals process changes long before specifications are exceeded.

Examples include:

- Gradual dryer degradation.
- Resin lot variation.
- Additive dosing drift.
- Equipment wear.
- Seasonal process variation.

This transforms color measurement from a reactive quality activity into a proactive process-control tool.

### Using Color Measurement for Process Control

The most successful organizations utilize color measurements as part of their overall process-control strategy.

Measurements are often collected at regular intervals and reviewed alongside other process variables such as:



- Dryer performance.
- Melt temperature.
- Injection pressure.
- Cycle time.
- Resin moisture content.
- Additive feed rates.

When color data is viewed in conjunction with process data, it often becomes easier to identify root causes and improve overall process stability.

### **Developing Standard Operating Procedures**

Documented procedures are critical to maintaining consistency across shifts, operators, and facilities.

A typical SOP should define:

- Sample selection.
- Sample preparation.
- Measurement location.
- Instrument settings.
- Standardization frequency.
- Acceptance criteria.
- Data recording requirements.
- Escalation procedures.

Well-documented procedures help ensure that measurements remain consistent over time and support internal audits, customer audits, and quality management requirements.

### **Building a Culture of Measurement**

The most effective color quality programs view measurement as a process-improvement tool rather than simply a quality inspection requirement.



When operators, engineers, and quality personnel understand how color data relates to process performance, measurements become valuable information rather than numbers collected solely for compliance purposes.

Organizations that embrace this approach often experience:

- Improved process stability.
- Faster troubleshooting.
- Reduced waste.
- Better customer satisfaction.
- Greater confidence in product quality.

### Key Takeaway

Implementing a successful color measurement program requires more than simply purchasing an instrument. Manufacturers must establish standards, define tolerances, standardize measurement procedures, and utilize trend analysis to transform color data into actionable process intelligence. When properly implemented, color measurement becomes a powerful tool for improving consistency, reducing quality costs, and strengthening overall manufacturing performance.

## Vista® L2: A Practical Solution for Transparent Preform Color Measurement

Successful preform color measurement requires more than simply collecting data. Manufacturers need a measurement system that provides accurate, repeatable, and actionable information while fitting seamlessly into routine production quality control activities.

For transparent PET preform applications, HunterLab recommends the **Vista® L2**, a transmission spectrophotometer specifically designed for measuring transparent and translucent materials.

Vista L2 allows manufacturers to objectively evaluate color, yellowness, whiteness, and appearance characteristics of transparent packaging materials while providing the speed and simplicity required for production environments.

### Designed for Transparent Materials



Unlike instruments optimized for opaque materials, Vista L2 is specifically designed for transmission measurements.

Typical applications include:

- PET preforms.
- Transparent bottles.
- Pharmaceutical solutions.
- Liquid chemicals.
- Edible oils.
- Beverage products.
- Transparent packaging materials.
- Water and process liquids.

Because preforms are transparent rather than opaque, transmission measurement provides a direct evaluation of how light passes through the material and how the package will ultimately appear to consumers.

### **Key Measurements for Preform Applications**

Vista L2 provides a variety of measurements commonly used throughout the packaging industry.

### **CIELAB Color Values**

CIELAB remains one of the most widely used color spaces for packaging applications.

Measurements include:

- L\* (Lightness)
- a\* (Red-Green Axis)
- b\* (Yellow-Blue Axis)

These values provide a standardized method for monitoring color consistency and communicating requirements throughout the supply chain.

### **Yellowness Index**



Yellowness Index is particularly valuable for transparent PET applications because it provides a sensitive indicator of:

- Thermal degradation.
- Resin variation.
- Processing issues.
- Material aging.

Many manufacturers routinely monitor Yellowness Index as part of their process-control strategy.

### **Whiteness Index**

Whiteness Index may be used when evaluating highly transparent or near-colorless materials where subtle appearance differences can be important.

### **Delta E ( $\Delta E$ )**

$\Delta E$  provides a numerical comparison between a production sample and an established standard.

This allows manufacturers to quantify color differences and determine whether production remains within specification.

### **Monitoring Oxygen Scavenger Systems**

One of the most valuable applications of Vista L2 in PET packaging involves monitoring oxygen scavenger systems.

Many oxygen-sensitive beverages require packaging that helps protect product quality throughout the intended shelf life.

Because oxygen scavengers frequently influence the optical properties of the preform, color measurements can provide useful process-control information.

In many applications:

- Increased oxygen scavenger concentration results in reduced  $L^*$  values.
- Color measurements help verify additive consistency.
- Trend analysis helps identify process variation.



- Measurements provide rapid, non-destructive feedback.

This allows manufacturers to monitor process consistency without interrupting production.

## Supporting Quality Control and Process Improvement

Vista L2 can support multiple quality objectives simultaneously.

### Production Quality Control

Routine measurements help verify:

- Product consistency.
- Specification compliance.
- Lot-to-lot repeatability.
- Customer requirements.

### Process Monitoring

Color trends often provide early indication of:

- Dryer performance changes.
- Thermal degradation.
- Material variation.
- Additive dosing variation.

### Supplier Quality Management

Objective measurements provide a common language for communicating requirements between:

- Resin suppliers.
- Preform manufacturers.
- Bottle producers.
- Brand owners.

This improves consistency throughout the supply chain and reduces disputes regarding appearance.



## User-Friendly Operation

Production quality control programs depend on obtaining reliable measurements consistently across multiple operators and shifts.

Vista L2 is designed to simplify routine operation through:

- Guided workflows.
- Touchscreen operation.
- Fast measurement cycles.
- Digital data storage.
- Automated calculations.
- Quality control reporting.

These capabilities help reduce operator variability while improving productivity.

## Integrating Bottle Haze Measurements

Although Vista L2 is primarily used for transmission color measurement of preforms, it can also support bottle clarity evaluations when appropriate flat bottle cutouts are prepared.

By combining:

- Preform color measurements.
- Bottle haze measurements.
- Historical trend analysis.

manufacturers can develop a more complete understanding of package appearance and process performance.

This approach allows color and clarity to be managed as complementary quality attributes rather than independent measurements.

## Business Benefits

Organizations implementing objective color measurement programs often report benefits such as:

- Reduced scrap and rework.



- Improved process consistency.
- Faster troubleshooting.
- Improved supplier quality.
- Reduced customer complaints.
- Better documentation and traceability.
- Improved sustainability initiatives.

Because color is measured at the preform stage, many quality issues can be identified before significant downstream costs are incurred.

### **Key Takeaway**

Vista® L2 provides a practical solution for transparent PET preform color measurement by delivering accurate transmission color data, CIELAB measurements, Yellowness Index, Whiteness Index, and  $\Delta E$  analysis in a production-friendly platform. By measuring color at the preform stage and utilizing bottle cutouts for haze evaluation when needed, manufacturers can improve process control, reduce quality costs, and maintain consistent package appearance throughout the production process.

## **Common Applications for Preform Color Measurement**

While the fundamental principles of color measurement remain the same, the specific quality objectives often vary depending on the final package application. Different products have different appearance requirements, shelf-life objectives, regulatory considerations, and customer expectations.

As a result, manufacturers often utilize color measurement differently depending on the type of package being produced.

### **Bottled Water**

Bottled water represents one of the most demanding applications for transparent packaging.

Consumers expect bottled water containers to appear:

- Clear.
- Clean.



- Colorless.
- Consistent.

Even slight variations in color can become noticeable when bottles are displayed together on retail shelves.

For bottled water applications, color measurement is commonly used to:

- Monitor resin consistency.
- Detect yellowing.
- Verify production stability.
- Support supplier quality programs.
- Maintain package appearance standards.

Because bottled water packages are often highly transparent, maintaining consistent color is critical to consumer perception and brand image.

### **Carbonated Soft Drinks (CSD)**

Carbonated beverage packaging introduces additional considerations due to product carbonation requirements and production volumes.

Manufacturers often utilize color measurement to:

- Verify preform consistency.
- Monitor process stability.
- Evaluate resin changes.
- Control package appearance across multiple production facilities.

Because CSD production frequently operates at high volumes, early detection of process variation can provide significant quality and cost benefits.

### **Juice and Sensitive Beverage Packaging**

Juices, teas, sports drinks, and nutritional beverages often require enhanced oxygen protection to maintain flavor stability and shelf life.

These applications frequently utilize oxygen scavenger technologies.



As discussed previously, oxygen scavenger concentration can influence preform color, particularly  $L^*$  values.

Color measurement is commonly used to:

- Verify oxygen scavenger loading consistency.
- Monitor additive dosing.
- Evaluate lot-to-lot variation.
- Support process validation activities.

In these applications, color measurement functions as both a quality-control and process-monitoring tool.

### Hot-Fill Packaging

Hot-fill applications expose packaging materials to elevated temperatures during production.

Examples include:

- Juice products.
- Tea beverages.
- Sports drinks.
- Functional beverages.

Because elevated temperatures can influence material appearance, manufacturers often monitor color to identify:

- Thermal degradation.
- Processing variation.
- Material performance changes.

Trend analysis can help identify developing issues before they impact finished package quality.

### Multi-Plant Manufacturing Operations

Many packaging manufacturers operate multiple production facilities across different regions.



Maintaining appearance consistency across facilities can be challenging due to variations in:

- Equipment.
- Operators.
- Resin sources.
- Environmental conditions.

Objective color measurement provides a common language that allows facilities to compare performance and maintain consistent quality standards.

By utilizing standardized measurement methods, organizations can improve consistency regardless of where products are manufactured.

### **Supplier Qualification and Incoming Material Inspection**

Color measurement is frequently used as part of supplier quality programs.

Applications include:

- Resin qualification.
- Supplier comparisons.
- Incoming material verification.
- Corrective action investigations.
- Material approval programs.

Objective measurements provide a documented method for evaluating supplier performance and reducing disputes related to material appearance.

### **Process Troubleshooting**

Color measurements are often among the first indicators that a process has changed.

Examples include:

- Unexpected increases in yellowness.
- Changes in L\* values.
- Gradual color drift.



- Increased lot-to-lot variation.

When these changes occur, manufacturers can investigate potential causes such as:

- Dryer performance.
- Material handling.
- Additive systems.
- Processing conditions.
- Equipment maintenance requirements.

Because color often changes before other defects become apparent, it can serve as an effective early-warning indicator for troubleshooting activities.

### **Sustainability and Process Optimization**

As manufacturers continue pursuing sustainability initiatives, process optimization becomes increasingly important.

Color measurement can support these efforts by helping organizations:

- Reduce scrap.
- Reduce rework.
- Improve process consistency.
- Improve material utilization.
- Reduce unnecessary waste.
- Increase confidence in production decisions.

By identifying variation earlier, manufacturers can often reduce the overall cost of quality while supporting broader sustainability goals.

### **Key Takeaway**

Preform color measurement supports a wide range of applications, from bottled water and carbonated beverages to oxygen-sensitive products and multi-plant manufacturing operations. Regardless of the application, objective color measurement provides manufacturers with a powerful tool for monitoring consistency,



improving process control, troubleshooting production issues, and maintaining the appearance standards expected by customers and brand owners.

## Business Benefits of Preform Color Measurement

While color measurement is often implemented to support product quality, its benefits extend far beyond simple pass/fail inspection. When integrated into a broader quality and process-control strategy, objective color measurement can help manufacturers improve operational efficiency, reduce costs, strengthen supplier quality programs, and enhance customer satisfaction.

For many organizations, the greatest value of color measurement comes not from identifying bad product, but from preventing bad product from being produced in the first place.

### Reducing Scrap and Rework

One of the most immediate benefits of preform color measurement is the reduction of scrap and rework.

When color variation is detected at the preform stage, manufacturers can often identify and correct process issues before large quantities of bottles are produced.

Potential issues may include:

- Resin variation.
- Additive dosing problems.
- Dryer performance issues.
- Processing temperature changes.
- Equipment malfunctions.

Because preforms represent an early stage in the manufacturing process, corrective actions taken at this point are generally far less expensive than corrections made after bottles have been blown, filled, packaged, and shipped.

### Improving Process Stability

Consistent color measurements are often an indication of a stable manufacturing process.



By routinely monitoring color trends, manufacturers can identify:

- Process drift.
- Equipment wear.
- Material variation.
- Environmental influences.
- Emerging quality issues.

This allows organizations to shift from a reactive approach to a proactive approach, identifying issues before they exceed specifications or affect customers.

Many facilities utilize color measurement as part of their broader Statistical Process Control (SPC) initiatives.

### **Supporting Continuous Improvement**

Objective measurements provide data that can be analyzed, trended, and used to drive improvement initiatives.

Rather than relying on subjective observations, organizations gain access to quantifiable information that can be used to:

- Evaluate process changes.
- Measure improvement efforts.
- Compare production lines.
- Benchmark facility performance.
- Validate corrective actions.

This data-driven approach often improves decision-making throughout the organization.

### **Reducing Customer Complaints**

Appearance-related complaints can be expensive and time-consuming to investigate.

Color measurement provides a documented, objective method for demonstrating product conformity and investigating potential issues.

Benefits include:



- Improved product consistency.
- Better documentation.
- Faster root-cause investigations.
- Improved customer confidence.
- Reduced disputes regarding appearance.

Many organizations find that objective color data helps improve communication between suppliers, manufacturers, and customers.

### **Improving Supplier Quality Management**

Color measurement also plays an important role in supplier quality programs.

Objective specifications allow manufacturers to:

- Qualify suppliers.
- Verify incoming materials.
- Monitor supplier consistency.
- Establish measurable performance criteria.
- Support corrective action programs.

By utilizing objective measurements rather than subjective visual evaluations, organizations can reduce ambiguity and improve supplier accountability.

### **Supporting Regulatory and Quality Requirements**

Many organizations operate under formal quality management systems that require documented verification of product performance.

Color measurement can support:

- Quality audits.
- Supplier audits.
- Customer audits.
- Internal quality programs.
- Documentation requirements.



- Traceability initiatives.

Because measurements are objective and repeatable, they provide a defensible method for demonstrating product conformity.

### **Improving Sustainability Initiatives**

Reducing waste is both an economic and environmental objective.

When manufacturers identify process variation earlier, they can often:

- Reduce scrap generation.
- Reduce rework.
- Improve material utilization.
- Lower energy consumption.
- Improve overall manufacturing efficiency.

These improvements not only reduce costs but also support broader sustainability and environmental goals.

### **Typical Return on Investment**

Though exact numbers vary significantly by customer, application, production volume, and region, organizations implementing objective color measurement often report savings through:

- Reduced scrap and rework.
- Improved process consistency.
- Reduced customer complaints.
- Improved supplier quality.
- Reduced troubleshooting time.
- Improved production efficiency.

In many preform manufacturing operations, the prevention of a single significant quality event can justify the investment in a color measurement system.

For high-volume production facilities, payback periods are often measured in months rather than years.



## Color Measurement as a Process-Control Tool

Perhaps the most important shift organizations can make is viewing color measurement as a process-control tool rather than simply a quality inspection tool.

When measurements are used only to determine pass/fail status, much of their value is lost.

When measurements are used to monitor trends, identify process changes, and support continuous improvement, color measurement becomes an active contributor to manufacturing performance.

This perspective often delivers the greatest long-term return on investment.

### Key Takeaway

The business benefits of perform color measurement extend well beyond appearance verification. By improving process stability, reducing waste, supporting supplier quality programs, enhancing customer satisfaction, and enabling data-driven decision making, objective color measurement can provide significant operational and financial value throughout the manufacturing process.

## Recommended Best Practices for Perform Color Measurement

Implementing a spectrophotometric color measurement program is not simply a matter of purchasing an instrument. The accuracy, repeatability, and usefulness of the resulting data depend heavily on the measurement procedures, sampling methods, and quality practices established by the organization.

The following best practices can help manufacturers maximize the value of color measurement while improving consistency and confidence in the results.

### Establish Clear Measurement Objectives

Before implementing a color measurement program, manufacturers should clearly define what they are attempting to control.

Common objectives include:

- Maintaining color consistency.



- Monitoring oxygen scavenger loading.
- Controlling yellowness.
- Verifying supplier quality.
- Supporting customer specifications.
- Detecting process variation.

Understanding the purpose of the measurement program helps determine appropriate standards, tolerances, sampling frequencies, and reporting requirements.

### **Use Approved Production Standards**

Color standards should represent the appearance of an approved product.

Whenever possible, standards should be based on:

- Customer-approved samples.
- Approved production lots.
- Master reference standards.
- Controlled digital standards.

Standards should be protected from contamination, damage, and environmental exposure to ensure long-term stability.

Organizations should also establish documented procedures for standard review and replacement.

### **Develop Meaningful Tolerances**

A tolerance should reflect both customer expectations and manufacturing capability.

Excessively tight tolerances can generate unnecessary rejects, while overly broad tolerances may allow unacceptable variation to pass undetected.

Common approaches include monitoring:

- $\Delta E$
- $L^*$
- $a^*$



- $b^*$
- Yellowness Index
- Whiteness Index

Many organizations begin by evaluating historical production data to determine realistic tolerance limits before implementing formal specifications.

### **Standardize Sample Presentation**

Consistent sample presentation is critical to achieving repeatable measurements.

Measurement procedures should define:

- Sample orientation.
- Measurement location.
- Fixture usage.
- Number of measurements.
- Data averaging requirements.

When multiple operators, shifts, or facilities are involved, standardized procedures help reduce measurement variability and improve confidence in the results.

### **Measure Representative Samples**

The objective of quality control is to evaluate the process, not simply a single preform.

Sampling plans should ensure that measurements represent the overall production lot.

Factors to consider include:

- Production volume.
- Lot size.
- Process capability.
- Historical variation.
- Customer requirements.



Many manufacturers utilize multiple samples and average results to obtain a more representative assessment of production quality.

### **Trend Data, Don't Just Collect It**

One of the most common mistakes in quality programs is treating color measurement as a simple pass/fail activity.

The greatest value often comes from trend analysis.

Tracking measurements over time can reveal:

- Process drift.
- Equipment wear.
- Material variation.
- Additive dosing changes.
- Emerging quality issues.

Trend analysis allows organizations to identify and address problems before specifications are exceeded.

### **Utilize Statistical Process Control (SPC)**

Color measurements can be integrated into broader Statistical Process Control programs.

Monitoring control charts for:

- $L^*$
- $b^*$
- Yellowness Index
- $\Delta E$

can provide early indication of process changes that may not yet be visible in finished products.

Many manufacturers find that color measurements serve as a highly sensitive indicator of process performance.

### **Correlate Measurements to Product Performance**



Measurements should always be linked to real-world outcomes.

For example:

- Changes in  $L^*$  may correlate with oxygen scavenger loading.
- Changes in  $b^*$  may correlate with yellowing.
- Changes in Yellowness Index may correlate with thermal degradation.
- Color shifts may correlate with customer appearance concerns.

Understanding these relationships helps transform color measurements into actionable process information.

### **Standardize Instrument Maintenance**

Routine instrument maintenance helps ensure measurement reliability.

Recommended practices include:

- Following manufacturer standardization procedures.
- Maintaining certified reference standards.
- Keeping optical surfaces clean.
- Documenting maintenance activities.
- Performing annual calibration verification.

### **Standardization vs. Calibration**

It is important to understand the difference between standardization and calibration.

**Standardization** is a routine procedure performed by the user to establish a measurement baseline and compensate for normal environmental and instrument changes.

**Calibration verification** is a formal process used to confirm that the instrument remains traceable and performs within specification.

HunterLab recommends:

- Standardization according to instrument prompts and operating procedures.



- Annual calibration verification as part of a comprehensive quality management program.

### **Train Operators Consistently**

Even the best measurement system can produce inconsistent results if operators follow different procedures.

Training should cover:

- Instrument operation.
- Sample presentation.
- Standardization procedures.
- Data interpretation.
- Escalation procedures.
- Documentation requirements.

Consistent training improves measurement repeatability and strengthens confidence in the resulting data.

### **Integrate Color Measurement into Continuous Improvement**

The most successful organizations view color measurement as a process-improvement tool rather than simply a quality inspection requirement.

Color data can support:

- Root-cause investigations.
- Process optimization.
- Supplier management.
- Cost reduction initiatives.
- Sustainability programs.
- Continuous improvement activities.

When integrated into broader operational strategies, color measurement often delivers value far beyond appearance verification alone.



## Key Takeaway

Successful preform color measurement programs are built on consistent procedures, representative sampling, meaningful tolerances, and routine trend analysis. By combining objective measurements with sound quality practices, manufacturers can improve process stability, reduce quality costs, and gain greater insight into overall manufacturing performance.

## Conclusion

Transparent PET preforms represent a critical control point within the bottle manufacturing process. Because every finished bottle begins as a preform, the ability to monitor color at this stage provides manufacturers with valuable insight into material quality, additive performance, process stability, and overall manufacturing consistency.

Objective color measurement enables manufacturers to move beyond subjective visual inspection and establish a data-driven approach to quality control. By monitoring key parameters such as CIELAB values, Yellowness Index, Whiteness Index, and  $L^*$ , manufacturers can identify process variation earlier, verify oxygen scavenger loading, improve supplier quality management, and maintain more consistent package appearance.

One of the most important concepts discussed throughout this paper is the distinction between color measurement and haze measurement. While color can be measured directly on the preform and serves as an effective early indicator of process performance, haze should be evaluated on a representative blown bottle cutout rather than the preform itself. This approach provides more meaningful results, better repeatability, and improved correlation to actual package appearance while aligning with established haze measurement practices.

For transparent preform applications, the HunterLab **Vista® L2** provides a practical and effective solution for transmission color measurement. By combining objective color data with established quality procedures, representative sampling, and routine trend analysis, manufacturers can transform color measurement from a simple inspection activity into a powerful process-control tool.

The greatest value of color measurement is not merely determining whether a product passes or fails specification. Its true value lies in identifying process changes before



they become quality problems. By detecting variation earlier in the manufacturing process, organizations can reduce scrap, minimize rework, improve efficiency, strengthen customer satisfaction, and support continuous improvement initiatives.

As packaging manufacturers continue to pursue higher quality standards, increased production efficiency, and greater sustainability, objective color measurement will remain an essential component of modern quality control programs. When implemented correctly, preform color measurement provides the visibility needed to make better decisions, improve process consistency, and deliver the appearance quality that customers and consumers expect.

### **Key Takeaway**

Measure color on the preform. Measure haze on the bottle. Use objective data to detect variation early, improve process control, and maintain consistent package appearance. By combining best-practice measurement methods with the Vista® L2 transmission spectrophotometer, manufacturers can build a robust color quality program that supports quality, efficiency, and long-term business success.