THE SCIENCE OF UV PROTECTION IN PACKAGING

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INTRO

In a world increasingly depending on effective packaging for preserving and transporting a myriad of products, the role of ultraviolet light (UV) protection becomes paramount. UV radiation, an invisible threat, can significantly degrade the quality of contents within packaging, from food and beverages to pharmaceuticals and therefore significantly reducing the product shelf life. This whitepaper explores the intricate science behind UV protection in packaging, focusing on preserving the quality and longevity of the packaged products. By exploring the mechanisms of UV degradation and the innovative solutions available, particularly highlighting Holland Colours' LightGuard portfolio, we aim to shed light (pun intended) on the importance of UV blockers in maintaining product integrity and extending shelf life as well as showcasing the many options available.

THE FUNDAMENTALS OF UV PROTECTION IN PACKAGING

UNDERSTANDING UV RADIATION

Ultraviolet (UV) radiation is a form of electromagnetic radiation with wavelengths shorter than visible light but longer than X-rays. It plays a critical role in numerous natural and artificial processes. Exposing packaging and its contents can lead to significant damage, necessitating the incorporation of UV protection measures.

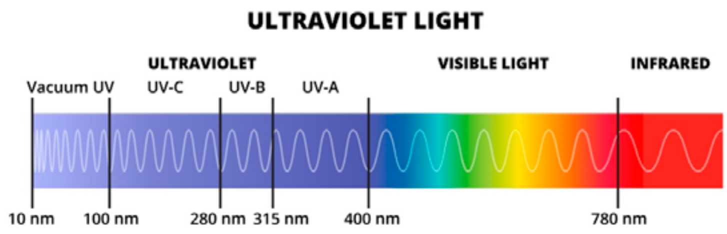

Figure 1 The ultraviolet, visible and near infrared spectrum

The UV radiation spectrum in the image above is categorized into three main types based on their respective wavelengths:

1. **UV-A (ULTRAVIOLET A):** UV-A, with the longest wavelength range (315-400 nm), comprises the most prevalent form of UV radiation reaching Earth's surface, accounting for approximately 95% of total UV exposure. UV-A's deep penetration into packaging materials and product contents can cause various degradation effects, including:
   - **Color Fading:** UV-A interacts with pigments and dyes, causing them to decompose and lose their color vibrancy. This is particularly detrimental to products with vibrant colors, such as cosmetics and beverages.
   - **Deterioration of Product Contents:** In sensitive products like pharmaceuticals and food items, UV-A can induce chemical reactions that alter their properties and reduce their efficacy.
2. **UV-B (ULTRAVIOLET B):** UV-B, with a shorter wavelength range (280-315 nm), is less abundant than UV-A, accounting for approximately 5% of total UV exposure. While its intensity is lower than UV-A, UV-B can still cause significant damage to packaging and its contents:
   - **Photochemical Reactions:** UV-B triggers photochemical reactions in packaging materials, leading to the formation of byproducts that can affect the packaging's properties and integrity.
   - **Degradation of Product Ingredients:** In food and pharmaceutical products, UV-B can break down sensitive ingredients, affecting their quality, taste, and shelf life.
3. **UV-C (ULTRAVIOLET C):** UV-C, with the shortest wavelength range (100-280 nm), is the most energetic form of UV radiation but is almost completely absorbed by Earth's atmosphere. Only a tiny fraction reaches the surface. However, if exposure occurs, UV-C can cause severe damage to packaging and its contents:
   - **Cellular Damage:** UV-C can damage cells and DNA, leading to cell death and potential mutations. This poses a threat to the safety of packaged goods, particularly those intended for consumption.

LIGHT SOURCES

Different light sources have a different distributions of wavelength intensities (See Figure 2) and some even absence of e.g., UV radiation. Solar radiation has a mayor UV-A and UV-B component. Artificial lighting has many variations, incandescent and fluorescent lighting have a small but significant UV-A contribution, but are nowadays almost completely replaced by LED lighting. These differences should be taken into consideration when designing protective packaging to make sure the correct wavelengths are being blocked.

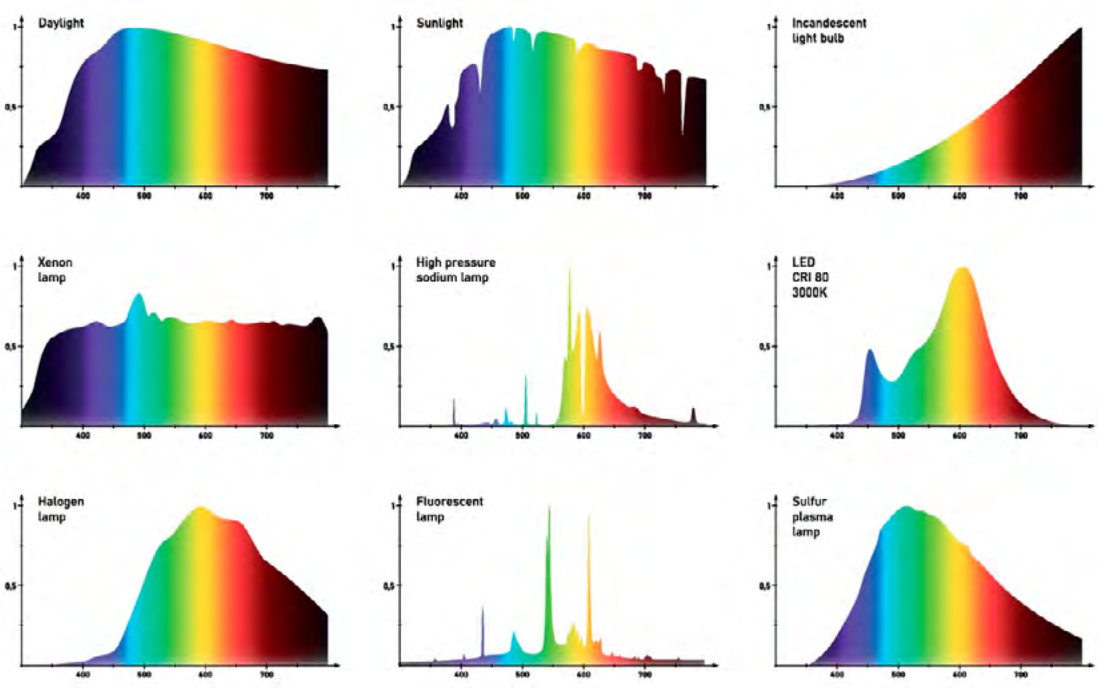

Figure 2 Radiation intensity spectra of different common light sources

IMPACT OF UV RADIATION ON THE PRODUCTS INSIDE THE PACKAGING

UV radiation can have a detrimental impact in various ways:

- **Quality Degradation:** UV radiation can cause products to degrade in quality, affecting their appearance, flavor, texture, and nutritional value. For instance, UV radiation can damage colorants in food or detergent products, alter the color and structure of cosmetics, and reduce the shelf life of pharmaceuticals.
- **Reduced Shelf Life:** UV radiation can shorten the shelf life of products by accelerating their degradation processes. This can increase inventory cost, affecting the overall efficiency of supply chains.
- **Spoilage and Loss:** UV radiation can accelerate the spoilage of food and beverages by causing oxidation and nutrient breakdown. This can lead to food waste and financial losses for businesses.

THE NEED FOR UV PROTECTION

This sub-section provided more background, highlighting the impact of UV radiation on product degradation, with a particular focus on products most susceptible to UV damage.

EXAMPLES OF COMMERCIAL PRODUCTS THAT USE UV BLOCKERS

UV blockers are incorporated into a wide range of commercial products, including:

- **Food and beverage packaging:** Beverage bottles, food containers, and packaging films. This can be found in products for milk, beer, juices, tea etc.
- **Cosmetic packaging:** Cosmetic bottles, tubes, and jars such as for hair oil products, make up, etc.
- **Pharmaceutical packaging:** Pharmaceutical bottles, blisters, and blister packs.
- **Detergents:** This is also a relevant industry as the colorants used to color the liquid products are susceptible to degradation through UV irradiation.
- **Electronics packaging:** Protective sleeves, housings, and enclosures to prevent discoloration and degradation of the articles packaged inside.

The negative effects of UV exposure on packaged products are well-documented and known in the industry. It is clear that UV radiation has a detrimental effect on packaging content and it is necessary to incorporate UV blockers in packaging to get the best out of quality and shelf-life.

UNDERSTANDING **UV BLOCKERS AND THEIR MECHANISMS**

THE SCIENCE OF UV BLOCKERS: THE TYPES OF UV BLOCKERS

UV blockers play a crucial role in packaging by shielding the contents from the harmful effects of ultraviolet radiation. These compounds, primarily classified into organic and inorganic types, employ their own unique mechanisms to prevent UV penetration and safeguard the product inside the packaging.

Organic UV Blockers:
Organic UV blockers, such as benzotriazoles and benzophenones, excel at absorbing UV radiation and transforming it into harmless heat energy. Their effectiveness lies in conjugated pi-electron systems that are able to absorb UV photons. They allow for the creation of colorless and transparent packaging, although color can be added if desired.

Inorganic UV Blockers:
Inorganic UV blockers, like zinc oxide and titanium dioxide, operate on a different principle – reflection. These compounds scatter or reflect UV radiation, deflecting it away from the packaging and preventing it from reaching the product. Their effectiveness depends on their particle size and refractive index, which dictate their scattering efficiency. Inherently these blockers are opaque and thereby also cover the visible spectrum, adding broader protection for e.g., dairy products and other visible light sensitive products.

Selecting the Right UV Blocker:
The choice of UV blocker depends on various factors, including the product's sensitivity to UV and visible light radiation, the packaging material, and the desired level of protection. For products highly susceptible to UV degradation, organic UV blockers with broad-spectrum protection are preferred. For visible light sensitive products, inorganic UV blockers offer effective protection and can be easily incorporated into the packaging material.

INNOVATIONS IN UV BLOCKING TECHNOLOGY

The quest for improved UV protection is driving innovation in UV blocking technology. Recent advancements include the development of:

- **More sophisticated organic UV blockers:** These compounds boast enhanced UV absorption capabilities up to 390 nm, improved storage stability due to being a solid, and a higher molecular weight range, thereby reducing migration from the packaging.
- **Multi-Functional UV Blocker Additives:** Future trends in UV protection focus on the development of multi-functional additives. By combining multiple functionalities, these additives offer a more comprehensive and cost-effective solution for packaging protection. For example, Holland Colours has created multi-functional additives for customers, combining our Lightguard additives as well as a TintMask additive to combat the yellowing of rPET.

Continued research and development in UV blocking technology promise to deliver even more effective and versatile solutions, ensuring the safety and longevity of light sensitive products.

SHIELDING CONTENTS FROM UV DAMAGE WITH DIVERSE POLYMERS

PACKAGING MATERIALS AND UV BLOCKING EFFICIENCY

Various packaging materials are employed in the food, beverage, pharmaceutical, and other industries. Each material possesses unique characteristics and respective UV blocking capabilities, influencing the effectiveness in protecting the contents from UV damage. Of course, this is enhanced when combined with specific UV protecting additives.

This subsection delves into a comparative analysis of these materials, focusing on common packaging polymers like Polyethylene Terephthalate (PET), Polyvinyl Chloride (PVC), High-Density Polyethylene (HDPE), Polypropylene (PP), Polystyrene (PS), and others.

1. Polyethylene terephthalate (PET)
2. High-density polyethylene (HDPE)
3. Polyvinyl chloride (PVC)
4. Low-density polyethylene (LDPE)
5. Polypropylene (PP)
6. Polystyrene (PS)

Comparison of Different Packaging Materials:

A comparison of different packaging materials reveals distinct patterns in their UV blocking efficiency. The UV blocking properties of each polymer are largely related to the monomers in their backbone, whether the final polymer has double bonds, conjugated double bonds, aromatic groups and/or heteroatoms (i.e. oxygen, nitrogen, sulfur, chlorine).

Polyolefins such as polypropylene (PP) and polyethylene (PE) do not have any double bonds and therefore show minimal absorption in the UV range beyond 200 nm.

Polymers with aromatic groups like polycarbonate (PC) and polyethylene terephthalate (PET) already absorb all UV light up to 290 and 320 nm respectively, thereby only needing a limited additional blockage to be able to block the full UV range. By using Polyethylene naphthalate it is even possible to go up to 390 nm.

The ability of PET to absorb up to 320 nm combined with its availability and recyclability make it very suitable to combine with an additional UV blocker to create packaging with content protection for nearly the full UV range, while still appearing fully transparent.

CONSIDERATIONS FOR UV PROTECTION IN PACKAGING

When selecting packaging materials and UV blockers for a specific application, several factors should be considered:

- **Product Sensitivity to UV Radiation:** Products that are highly susceptible to UV damage, such as pharmaceuticals and cosmetics, require packaging materials with strong UV blocking capabilities.
- **Environmental Conditions:** The packaging material should be able to withstand the UV exposure it will encounter in its intended environment.
- **Packaging Material Compatibility:** UV blockers should be compatible with the packaging material and not affect its properties or performance.
- **Cost-Effectiveness:** The cost of UV blockers and their integration into packaging materials should be considered, balancing protection with cost-effectiveness.
- **Regulatory Requirements:** Packaging materials with UV blockers may need to adhere to specific regulatory requirements regarding their safety and environmental impact, especially regarding food contact. Organic UV blockers, such as benzotriazoles and benzophenones, absorb UV radiation and convert it into harmless heat energy. Several of these are currently under investigation to be classified as SVHC – substances of very high concern. If you'd like to know more, our product stewardship department can help you out.

By carefully considering these factors, packaging manufacturers can effectively shield the contents of their products from UV damage and ensure their quality and integrity throughout the supply chain.

GUIDELINES FOR SELECTING AND TESTING UV BLOCKERS FOR PRODUCT PROTECTION

The selection and testing of UV blockers should be meticulously tailored to the specific requirements of each packaged product. Here are some key considerations:

- **Product Sensitivity to UV Radiation:** The product's susceptibility to UV damage is a crucial factor to evaluate, which wavelength range has the most impact. For highly sensitive products, UV blockers offering broader-spectrum protection and higher concentrations may be necessary to ensure full protection. Looking at juices protection in the UV range may be sufficient, however, for beer, wine and milk also protection in the visible range is required for longer term product protection.
- **Desired Level of Protection:** The level of UV protection required varies depending on the specific application and the environmental conditions the packaging may encounter. For extended shelf life in high-exposure environments, more effective UV blockers will be necessary. Transmission spectra measurements can be used to determine the amount of UV radiation transmitted through packaging material containing UV blockers. A low transmission indicates that the UV blocker is effectively absorbing UV radiation, preventing it from reaching the product and causing damage
- **Compatibility with Packaging Components:** The UV blocker should be compatible with other packaging components, such as adhesives, inks, and labelling, to avoid any adverse interactions that could compromise the packaging's integrity or appearance.
- **Long-Term Stability Testing:** Long-term stability testing is essential to guarantee that the UV blocker maintains its effectiveness throughout the product's shelf life. The product in the packaging containing the UV blocker is tested in a simulated environment over a longer period of time to determine the performance of the packaging. The simulation can include different light sources, humidity and temperature. After the period the product in the container is evaluated to check if is still fit for use. The analysis can include color and chemical analysis for degradation, physical analysis, as well as organoleptic evaluation (e.g., smell, taste, mouth feel).

LONG TERM BENEFITS OF SHIELDING PRODUCTS FROM UV DAMAGE

UV radiation poses a significant threat to the integrity and quality of packaged goods. Its exposure can lead to detrimental effects on product contents, compromising appearance, taste, nutritional value, and efficacy. By incorporating UV protection into packaging materials, manufacturers can safeguard the contents from UV damage, extending shelf life, enhancing consumer satisfaction, and realizing economic benefits. But what are the costs associated with proper UV protection and what does the ROI look like?

Economic Implications: A Cost-Benefit Analysis of Shielding Products from UV Damage

While the technical benefits of UV protection are clear, it is also critical to understand its economic impact. This subsection will provide a basic cost-benefit analysis of implementing UV protection in packaging, focusing on long-term savings and return on investment (ROI) considerations.

Cost vs. Savings

The initial investment in UV protection technologies, such as LightGuard, can vary depending on factors such as packaging materials, the extent of UV protection required, and the volume of packaging produced. However, these upfront costs are often outweighed by the substantial long-term savings that UV protection can deliver.

The primary financial benefits of UV protection is **reduced product degradation and spoilage**. By shielding products from UV radiation, manufacturers can **extend the shelf life** of their products, **minimizing spoilage losses** and associated costs.

Another notable economic advantage of UV protection is **reduced product recalls**. When products spoil due to UV exposure, manufacturers face the costly process of recalling and replacing affected items. UV protection can significantly reduce the frequency of product recalls, saving companies substantial resources and **reputational damage**.

Sustainability and Cost Savings

The environmental benefits of UV protection also contribute to a positive ROI. By **reducing packaging waste** and associated **disposal costs**, manufacturers can save money and enhance their **sustainability credentials**.

Consider a laundry detergent company that implements UV-protected packaging for its products. By extending the shelf life of the product by 10%, the company reduces the need to manufacture and transport new products as frequently. This translates into a reduction in greenhouse gas emissions and a positive impact on the environment.

In conclusion, the economic benefits of UV protection extend far beyond initial prodcutcosts. By extending shelf life, reducing spoilage losses, and minimizing product recalls, UV protection can yield significant financial savings. Additionally, adopting UV protection aligns with sustainability goals and contributes to a greener environment. By incorporating UV protection into their packaging solutions, companies can elevate their products to a new level of quality, sustainability, and economic viability.

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