

## Innovative Packaging to Life: The Magic of Photochromic and Fluorescent Nano-Inks in Modern Packaging Design as New Era in Consumer Experience

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### Abstract:

The packaging industry is increasingly exploring innovative approaches that merge functionality with consumer interactivity. However, a significant challenge remains in the limited application of smart nano inks particularly photochromic and fluorescent (FL) inks and sustainable for packaging printed based on water solvent. as functional design elements in packaging, especially for eco-friendly substrates. This research aims to overcome this limitation by developing and evaluating nano-scale photochromic and fluorescent inks based on acrylate resins, with water as the solvent medium, to create smart, sustainable packaging solutions. Two nano-ink formulations were synthesized and applied to both paper and plastic substrates. Comprehensive analyses including particle size, zeta potential, glossiness, whiteness, and dry rub color fastness were conducted before and after UV exposure. Results showed that fluorescent nano-inks exhibited higher stability (zeta potential  $-31.34$  mV), narrower particle size distribution as nano ink, and better gloss retention compared to photochromic counterparts. Both ink types maintained excellent rub resistance (Gray Scale rating of 5) across all substrates. However, significant UV-induced degradation was observed in whiteness and gloss for all samples, more prominently in photochromic inks. Visual tests confirmed the intended luminescent and color-changing properties of the inks under UV light. This study successfully demonstrates the feasibility of applying eco-friendly, interactive nano-inks in (PC) (FL) packaging to enhance both brand identity and consumer engagement. Future research should focus on improving UV resistance and exploring multi-stimuli responsive nano-inks to further elevate smart packaging technologies. In the modern world of packaging, functionality and aesthetics are integral to the success of a product's presentation and the enhancement of consumer experience. One significant innovation in the packaging industry is the use of photochromic and fluorescent inks. These inks are designed to exhibit unique properties that go beyond traditional printing, offering both functional and visual appeal. Photochromic ink (PC) inks change color in response to light, while fluorescent inks (FL) glow under ultraviolet (UV) light, offering packaging designers new tools to create dynamic, interactive, and highly engaging products. This paper explores the fundamentals of photochromic and fluorescent inks, their properties, and the innovative applications they offer in the packaging sector.

**Statement of the Problem:** The limitations of using special inks (fluorescent and photochromic) in printing of packaging label as distinctive features in label design. How to apply smart nano-inks in the field of packaging. The research problem lies in answering the following questions: What is the effect of using photochromic and fluorescent inks on printing of packaging label? How fluorescent and photochromic inks will be applied in innovative designs for packaging label?

**Objective:** The research aims to overcome the limitations of using fluorescent and photochromic inks in printing packaging label by utilizing them as smart, environmental friendly nano inks based on water as a solvent. It seeks to enhance the use of smart inks (photochromic and fluorescence) in printing of packaging label and to produce smart materials and their role in improving the efficiency of label production.

**Significance:** The importance of research lies in the global challenges in the field of packaging, through the addition of innovative future technology for printing of packaging labels using smart, environmental friendly nanomaterials that create added competitive value for products. The smart application can be utilized in many areas, providing design insights that are employed to improve the quality of label production within the packaging system.

**Hypothesis** - Provide an interactive smart ink that is eco-friendly for the Egyptian packaging market. - Evaluate the effectiveness of applying smart nano inks to packaging materials.

**Methodology** The research methodology follows an experimental research approach to study, examine, and evaluate the effect of photochromic smart inks and fluorescent inks used in packaging materials.

Photochromic and fluorescent inks can also support sustainability efforts. In some cases, these inks can be formulated with eco-friendly materials, making them more compatible with recycling processes. Moreover, their ability to function effectively under specific light conditions means that they may reduce the need for additional packaging materials, contributing to more sustainable production practices.

**Results:** The distinguished color of fluorescence ink as luminesce color with phosphoric color emission under UV- light. In addition, photochromic ink exhibits color under UV-lamp. These images confirm the visual light activity of FL and PC printing inks. From the results of the first hypothesis of the research is realized. Evaluated the effectiveness of applying smart nano inks to packaging materials was carried out as second hypothesis. The analysis highlights the clear influence of both substrate and inks type on gloss retention, especially under UV exposure. FL ink and paper substrates outperform their counterparts in maintaining surface gloss, suggesting their preferable use in applications where long-term aesthetic performance is required. Overall, printed FL seem more UV-stable than printed PC, though both suffered significant whiteness losses. Plastics are generally more vulnerable to UV-induced discoloration compared to papers. Color fastness to dry rubbing is excellent across all tested inks and substrates. UV exposure does not negatively affect dry rub performance. Both PC and FL inks are highly durable under mechanical dry rubbing, making them suitable for applications requiring handling and surface resistance without aesthetic compromise. This study successfully demonstrates the applicability of eco-friendly reactive nan oinks in packaging to enhance brand identity and consumer interaction. They can be applied to preserve the product's identity from counterfeiting.

### **Paper History:**

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Photochromic; Fluorescent; Nano-Ink; Innovative Design; Internet Packaging, Consumer Experience

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