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Accelerated photodegradation of dye-based ink-jet printing inks in an aqueous solution and on a substrate

Barbara Blaznik[1], Franci Kovač[2], Grega Bizjak[3], Sabina Bračko[1]
[1] University of Ljubljana, Faculty of Natural Sciences and Engineering; [2] University of Ljubljana, Faculty of Chemistry and Chemical Technology; [3] University of Ljubljana, Faculty of Electrical Engineering

Introduction

Photodegradation is an interactive process between light and material (Feller, 1994; Steiger et al, 1999). Among the most crucial factors affecting the lightfastness of colourants are dye concentration, degree of aggregation, pigment particle size, chemical and physical structure of the printing material, energy between the colourant and the printing material, spectral distribution of the light source and composition of the atmosphere, including relative humidity as well as the presence of pollutants in the air (Zollinger, 2003). Light fastness has long been of interest, nevertheless the photodegradation process has not been fully explained yet (Giles, 1965; Vikman et al, 2005). Exposure to a more significant proportion of UV radiation leads to accelerated chemical degradation of materials (Aydemir et al, 2018). Many processes accompanying the degradation of organic materials depend on temperature; therefore, the degradation rate is directly proportional to the increase in temperature (Blaznik et al, 2017). Also, the presence of oxygen in the surroundings negatively affects the degradation process. After all, oxidation is the fundamental reason for the decomposition of organic materials (Feller, 1994).

Problem Description

Prints made with an ink-jet printer represent a complex system in terms of print analysis, as they connect an infinite number of combinations of printing materials, colourants, and other internal and external factors (Jürgens, 1999). The purpose of our research was to study the photodegradation of ink-jet inks in an aqueous solution as well as prints made with an ink-jet printer under the influence of a high-pressure mercury lamp, which was used to accelerate the photodegradation process.

Methods

The Epson L130 (T2) printer with water-based ink-jet printing inks was used. Individual dye-based ink (C, M, Y, K) was taken directly from the cartridge and diluted 1:3000 with water. Also four colour fields (C, M, Y, K) with a resolution of 2400 dpi were printed on plain office (PPO) and permanent (TPI) paper. Before printing the roughness was measured on the upper side of the papers. For irradiation of water solutions of ink and prints a high-pressure mercury lamp was used (Figure 1). After the exposure, for the liquid samples, the measurements of absorption were performed. For prints, the measurements were performed in accordance with ISO 13655 and the colour differences were calculated using the CIEDE2000 equation. Moreover, the ink amount (IA) for aqueous solution and prints was calculated.

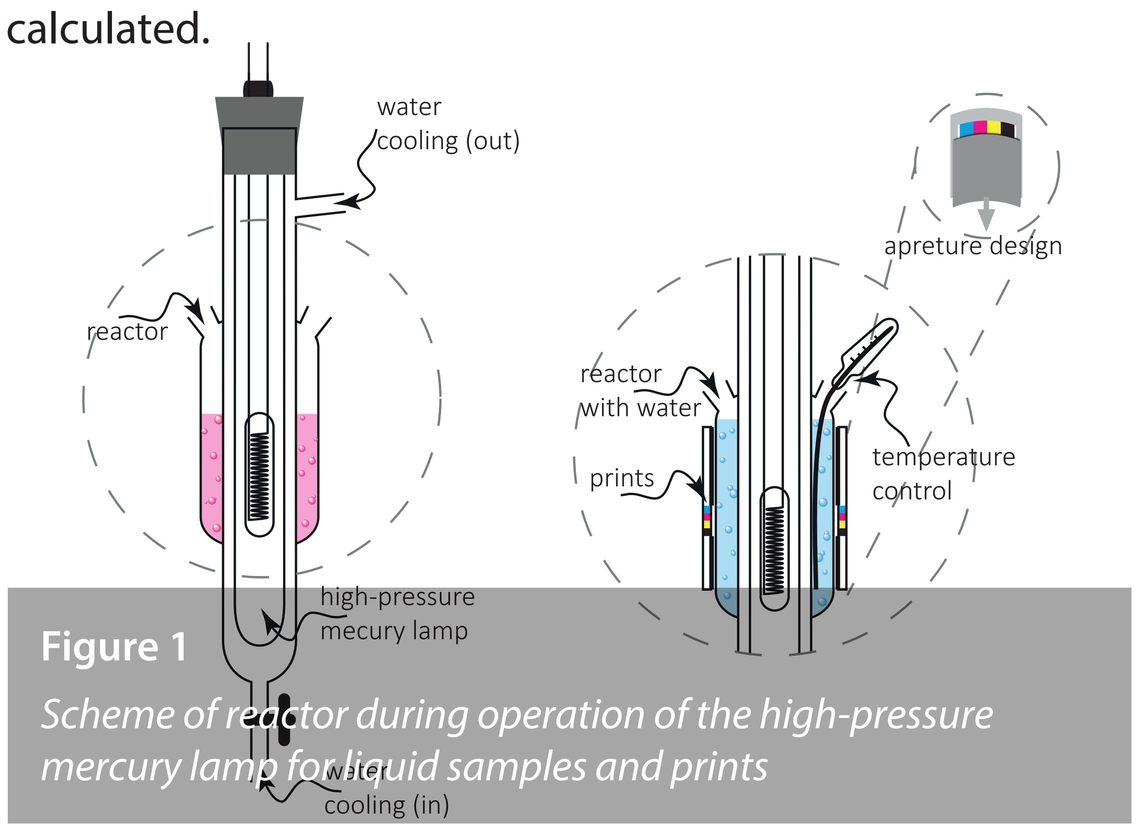

Figure 1
Scheme of reactor during operation of the high-pressure mercury lamp for liquid samples and prints

Results / Discussion

The IA values show that the most significant change after irradiation occurred with the black ink in an aqueous solution, as the amount decreased to 78 % of the initial absorbance. By monitoring the rate of photodegradation and calculating the slope (k) of the line, the degradation rate and half-life ($t_{1/2}$) were determined (Table 1). The photodegradation reaction likely follows the pseudo-first-order kinetic model for the best fit. The degree of photodegradation was most notable in the case of the black and yellow inks. On the other hand, the degradation of cyan ink was less evident.

Table 1

Ink amount (IA), coefficient (k) and half-life ($t_{1/2}$) of ink samples in aqueous solution under the influence of a high-pressure mercury lamp

	IA [%]	k [s^{-1}]	$t_{1/2}$ [min]
C	98	–0.0013	533
M	95	–0.0035	198
Y	84	–0.0118	59
K	78	–0.0165	42

Under the influence of the high-pressure mercury lamp, the so-called bronzing or red shift of cyan prints (Figure 2) occurred. Bronzing of cyan disappeared after 24 hours. The bronzing of prints is usually the result of the dye's structural characteristics and some external factors such as ozone (Bugner, 2002; Fujie et al, 2009), which was a by-product of the operation of the high-pressure mercury lamp. Therefore, the reflection of all prints and substrates was measured twice. Table 2 shows calculated values of ink amount (IA) and colour differences for the prints. Immediately after irradiation, the most significant changes in IA an ΔE^*_{00} are observed on the cyan prints due to the bronzing. Also, the positive influence of the printing material can be observed since, using a TPI paper, the IA values are higher. Magenta prints are considered the least durable; however, the use of TPI paper gave better results. The decrease of IA on magenta prints is significant both on TPI (IA = 81%) and even

Table 2

Colour difference (ΔE^*_{00}) of prints on office (PPO) and permanent paper (TPI) immediately and after 24 hours of exposure to the high-pressure mercury lamp

	Paper	IA [%]		ΔE^*_{00} [/]	
		imm.	after 24 h	imm.	after 24 h
C	PPO	94	98	2.27	1.05
	TPI	94	95	2.79	1.42
M	PPO	64	61	12.04	12.96
	TPI	81	81	5.25	5.47
Y	PPO	91	90	2.16	2.29
	TPI	95	95	1.22	1.09
K	PPO	97	98	1.15	0.82
	TPI	93	93	2.72	2.65

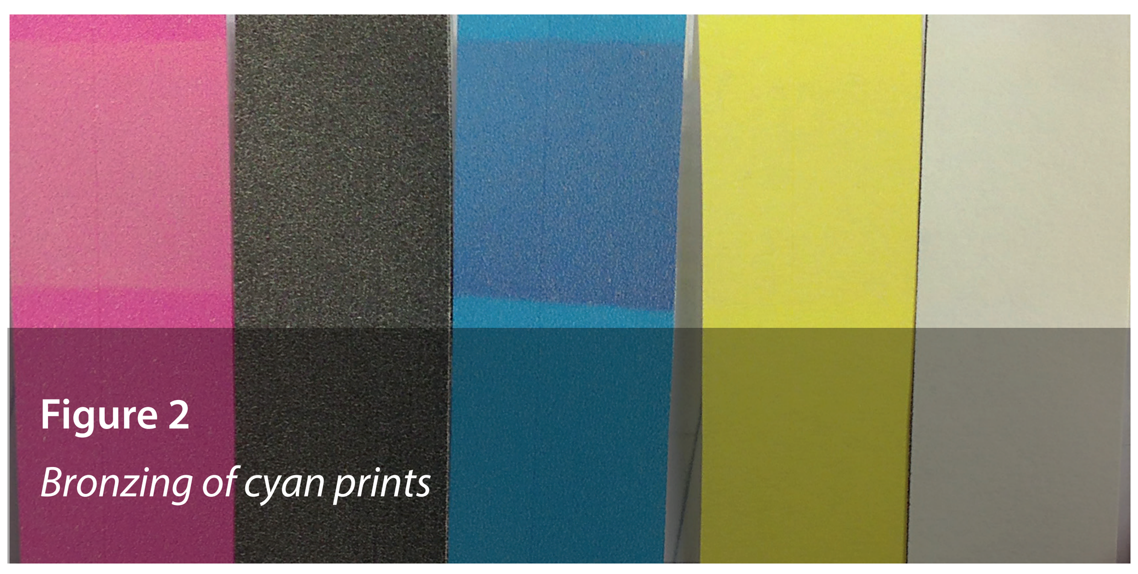

Figure 2
Bronzing of cyan prints

more on PPO paper (IA = 61%). Regarding the colour differences of the prints (Table 2), we find that, in line with expectations, the most significant colour differences occurred on magenta prints ($\Delta E^*_{00,M,PPO} > 12$ and $\Delta E^*_{00,M,TPI} > 5$). We can also find out how the value of ΔE^*_{00} changed 24 hours after the irradiation. A colour change can be observed, especially on cyan prints, resulting from the bronzing of the cyan print after irradiation with a UV lamp. In the case of magenta prints on paper PPO, notice that the ΔE^*_{00} increased by almost 1 after 24 hours of irradiation. Comparing the colour differences of prints on TPI paper, we can find that ΔE^*_{00} values immediately after irradiation and 24 hours after irradiation are somehow more constant compared to prints on PPO paper.

Conclusion

The degradation process of ink-jet inks in solution depends on internal factors such as the dye's chemical structure, the dyes' catalytic effect and the presence of various solvents in the accompanying liquid. According to the results, short-wave UV-C radiation had no significant impact on the cyan ink in the solution or the prints. However, bronzing of the cyan print indicates that several inter-related processes occur during the exposure to radiation, which can influence the durability of the prints and can also affect the testing procedure. In an aqueous solution, black ink exhibited inadequate durability, which was probably due to the catalytic effect due to some of the components, as black inks consist of a mixture of different colourants to achieve the desired colour shade. However, the same ink mixture printed on paper did not show as significant colour changes as in a solution. Surprisingly, the magenta in the solution proved to be relatively stable, but it still holds first place among the least durable inks on the print, regardless of the substrate used. Therefore, we conclude that when researching the fastness of prints, it is crucial to consider the composition of the ink, which is usually a mixture of several dyes that influence each other and behave unexpectedly in different environments. It is inevitable to consider both characteristics of dye or ink alone as well as its resistance and durability when applied to the substrate.

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