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To Predict the Waterfastness Rate of Foil Print

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***Abstract*— The study describes the waterfastness properties of foil prints which are exposed to water or rain. Waterfastness is one of the most important properties for any kind of print products for assessing their print stability. Poor waterfastness reduces the exposed lifetime of printed items in humid or rainy environments. Very few studies have been done on the fastness properties of printed film and foil substrate. In this work, blister foils printed in gravure process has been taken as the sample as it has immense usage in food and medicine packaging. Water immersion method and water spray test methods are carried out to study the waterfastness properties of the magenta foil ink and similar results are observed. The waterfastness properties are assessed by the evaluation of the measured spectral curves and colorimetric values before and after exposure using the oceanographic spectroradiometer (DH2000BAL) device. The results show a visible change in reflectance of the blue and red regions with time which claims the fading of magenta print with time due to long time exposure to water. This study has suggested a kinetic model to estimate the longevity of the printed foil .The optimal model has been obtained with a correlation coefficient of 0.93.**

Keywords*— *Waterfastness; Spectral data; CIE Lab; Gravure printing;

I. INTRODUCTION

Nowadays, customers are very much influenced by good packaging and convinced to buy the products due to the displayed information. The fading time of a print depends on ink and media properties and the environment in which the packages are kept. The color is an important parameter to evaluate the print quality. When this color or the printed image is degraded due to light, water or moisture, it may have negative effect on consumer mind. Print may fade from physical and chemical forces when they are exposed into water or weather. Water fastness can be defined as the resistance to color loss when a printed medium is immersed in or wiped with water. This is an important property, because the imaged media may be subjected to coffee spills, water spills, or even flooding. Color loss, with resultant loss of image quality, is mostly due to the solubilization of the dyes in the printed image. Sometimes the changes in color of packages help to find out the freshness and expiry of the products because different kinds of packaging materials used for food, confectionary and medicine packaging needed different types of storage condition from open market to deep freeze. Especially, the food or medicine package item may require long stability. The color stability plays an important role on packaging when they are exposed to the rain or water for a long period of time. Blister foil is one of the most important packaging media which is used extensively in food and medicine packaging due to its inertness and non-reactivity properties. This present study deals with the waterfastness performance of the printed foils. The temperature and relative humidity can affect the water resistance properties of the prints. Different models may describe the waterfastness properties of prints. It represents either hypothetical mechanism or can be empirically derived during laboratory experiments.

II. RELATED WORK

The subject of image stability has become considerably more complex in recent years. Appearance is the prime factor and most impressive product message to attract the customers' attention. So, the appearance of the product with time—its light fastness and water fastness—may also be crucial. Several praiseworthy studies are carried out to investigate the effects of the coating polymer system on the water fastness of soluble dyes on kaolin coated papers where the changes in color coordinates, color difference, physical properties are analyzed[1]. Moreover, FTIR and Raman spectra are also evaluated to understand the effect of the chemical interactions on water fastness. These studies further have investigated the mechanism of waterfastness of prints containing modified PCC and kaolin pigments, and model inks with known compositions. The water fastness and FTIR-Raman spectral data are analyzed using projection methods, namely principal component analysis (PCA) and projection to latent structures (PLS) [2]. After evaluation of paper properties and color difference, model based ink shows better waterfastness on cationic PVA-poly-DADMAC coatings than on weakly cationic styrene-acrylate latex-starch coatings. The water solubility of dyes leads to a cause of poor image water fastness. Therefore, the previous researches have suggested an approach to improve waterfastness attaching dyes chemically to the substrate surface during printing by coating the paper with silica pigments, poly vinyl alcohol binders (PVA),kaolin and cationic polymer additives[3,4,5]. It is stated that the addition of cationic starch in ink jet coatings with conventional pigments has enhanced the print quality. Fryberg et.al [6] has considered the dyes as the most important element of an ink contributing to image stability. The study has claimed that the controlled dye aggregation in the ink-receiving layer improves water fastness. Moreover, it is mentioned that the coating components also contribute waterfastness performance. Another study has taken attention focusing on the paper coating formulation to improve the water fastness property using an acrylic/nano silver resin in the ink's formulation [7]. The CIELab values are measured to show the changes in lightness and chroma due to water exposure where the results have clearly indicated that the lightness of the nano-composite ink is less than the acrylic emulsion ink. The evaluation of washfastness test is carried out to investigate the effect of reactive dye structure and the type of penetrant in ink formulation on different kinds of paper printing [8]. It is observed that the structure of reactive dyes, substrate type and the type of penetrant in ink's formulation all have influenced the penetration of ink into the paper. M. Stankovská et al.[9,10,11] have investigated the inkjet print quality which can be influenced by the surface sizing papers, coating color or pigment and binders. The results indicate that the water fastness of all sized papers has been improved due to surface sizing in comparison to base paper. Hence, the water fastness can be increased with increasing charge density of sizing agent. The extended work of this study has also suggested that the fixation of anionic dyes is necessary to improve water fastness by forming of complex with cationic polymer. Moreover, it is claimed that waterfastness is influenced by coating color. The two most critical elements for the water fastness of the t prints are the ink formulation and the composition of the receiving media which are described in details [12]. The study has addressed poor water fastness due to dye dissolve when there is no strong binding force holding the dye to the receiving medium. Therefore, the study has suggested using the cationic latex particles that can complex with anionic dyes to improve the water fastness. K. Kasahara[13] has taken attention to introduce a new drying technology for microporous glossy paper in printing in which paper has a good waterfastness. The color degradation has been analyzed with respect to time and temperature applying the first order kinetic model [14].A kinetic model has been also developed to assess the lightfastness properties [16].

Much of the previous researches have focused on the improving waterfastness properties of paper substrate, coating formulation or ink. In contrast, little or almost no work has been experienced with the waterfastness data on foil prints. But packaging industry specially associated with food and medicine packages have greatly used foil as an excellent media comparing to other media. Moreover, this paper has proposed a kinetic model to estimate the waterfastness properties of blister foil prints.

A. *Objectives*

The purpose of the present study is to assess the water fastness properties of foil prints with time. In this study, the effect of water on printed foils has been studied. This study has proposed a kinetic model to predict the waterfastness performance of printed blister foils based on the experimental data.

III. EXPERIMENTAL MATERIAL AND METHODS

Waterfastness Test is designed to see the resistance to water of dye, pigment or printed substrate. Water immersion and water spray test are used to evaluate the waterfastness properties of the foil prints as it is one of the most important packaging media. It is greatly preferred in food and medicine packaging due to its inertness and non-reactivity properties. The metallic luster and light weight are additional advantages of this material. It also enhances the shelf life of the food and medicine than if it is wrapped in plastic. The thickness of the foil is 25micron**.** Moreover, the advantageous features of gravure printing make it a very promising process for food and medicine package printing industry. So, the samples are printed with magenta foil ink by this printing process. The solvent based liquid ink is specially recommended for gravure foil prints. The prints are taken at 60meter/min speed. The printing press consists of an electronically engraved printing cylinder, blower, and heater. The drying temperature has been fixed at 50°-60°C for the printing .The experiment is done on 100% solid patch with screen frequency 152 lines per inch. All the samples are printed at same speed and pressure. The ambient temperature and humidity are 17 ± 3°C and 35±5% inside the press. The experiment is carried out with multiple samples. Fig. 1 describes the basic workflow of the water fastness study for magenta foil prints.

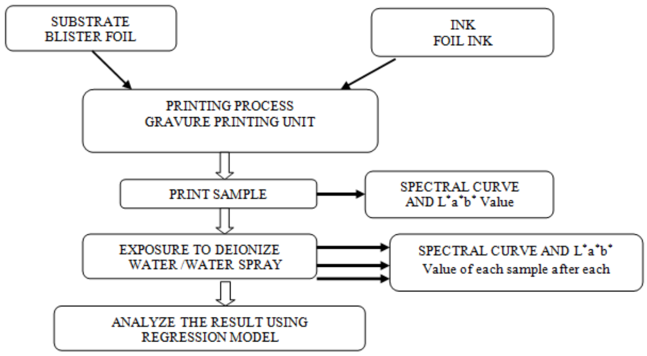

Fig. 1: Workflow diagram of the study

A. *Waterfastness Test*

Water immersion and Water spray test [17] are carried out to assess the waterfastness properties of the foil prints. Both the test methods are performed in the darkroom. In water immersion test method, multiple foil printed samples are immersed into a pan full of deionized water at room temperature. Then the samples are pulled out of the water after regular time interval, and are allowed to dry after blotting off the excess water. This method is advantageous as all the printed samples are evenly exposed to water. In water spray test method, the printed foil samples are allowed to expose to water shower at 45° angle with same speed and pressure. Also the samples are placed at same distance. The drying process is same like water immersion test.

B. *Measurements*

The present investigation has carried out a spectroscopic measurement by using Ocean Optic Spectrometer (DH2000BAL) with Tungsten Halogen and Deuterium lightsource**.** This device helps to record the spectral data which can be utilized to calculate CIE tristimulus values. CIE chromaticity coordinates and lightness can then be calculated. After print, the spectrophotometric curves and the L*, a* and b* values are collected using Ocean Optic Spectrometer (DH2000BAL) so that the values of reference sample are stored to understand the changes after exposure. The

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spectrophotometric curves of the exposed samples in water at different time intervals are measured using ocean optic spectroradiometer at 2° standard observer. For each sample, five readings are taken and average of five readings is calculated, rotating the sample between measurements. The measurement procedure is performed at 17°C-23°C and in absence of light. The five individual datasets have been prepared for the development of the kinetic model to check the performance accuracy of the model. Exposure time intervals are considered as the independent variables for the experiment and the reflectance values of the samples are the dependent variables.

C. Theories(Kinetic Model)

The present study has proposed a kinetic model in which it is stated that the rate of degradation of the color or fading is inversely proportional to its Reflectance at a particular wavelength. This is similar to the "first order kinetic model":

$$-\frac{dR}{dt} = kR \tag{1}$$

Where $-\frac{dR}{dt}$ is the rate of reflectance change, k is specific rate of constant for color changes in print samples. Eq. (1) has been presented in the integrated form:

$$\ln R = \ln R_0 - kt \tag{2}$$

Where, R is the Reflectance at a particular wavelength at a particular time interval t, and Ro is the initial reflectance at that specific wavelength at initial time. The rate constants at various wavelengths are found applying first order kinetic model. A regression analysis has been done to find the correlation coefficient.

D. Determination of Colorimetric Characteristics

The color difference is calculated by using the color coordinate values of unexposed and exposed print samples where the color coordinates L* represents lightness of prints, C* represents chroma and H represents hue . Then the color difference ΔE_{00} is assessed by applying CIE 2000 equation [15].

IV. RESULTS AND DISCUSSION

A. Evaluation of Spectral Distribution and Colorimetric Characteristics of Prints due to water

Fig. 2 shows the spectral characteristics of the printed foil before and after exposure to water at different time intervals. The color of the print samples is perceived by the reflectance of the samples in the visible range of spectrum. It is observed in Fig.2 that there is a sharp increase in reflectance in the blue zone and red zone which is clearly indicating the fading with time.

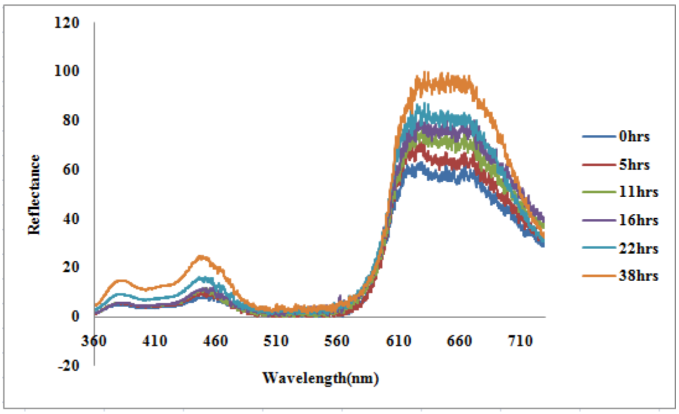

Fig. 2: Spectral data of fading on magenta print on blister foil

The lightness and chroma value play an important role to demonstrate the waterfastness properties of the prints. The variation of lightness L and chroma with time are illustrated in the Fig. 3 and Fig. 4 respectively. A sharp increase in the L values of the print is found in Fig. 3 indicating the fading of color. It is found in Fig. 4 that the chroma value is decreased with time.

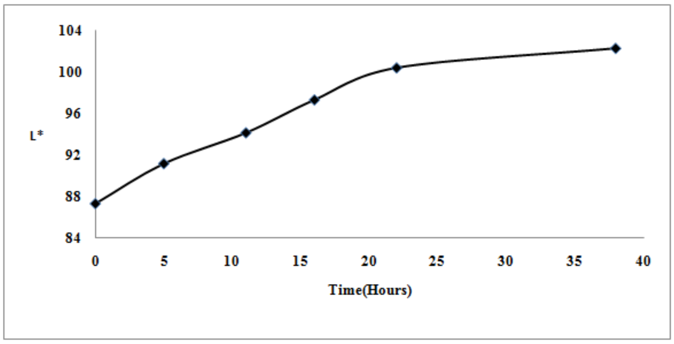

Fig. 3: Changes in L value of Printed blister foil

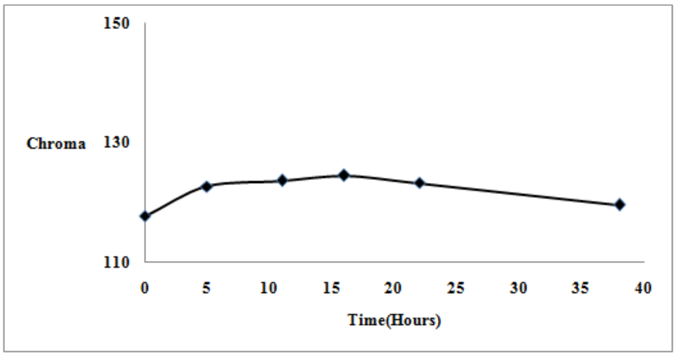

Fig. 4: Changes in Chroma value of Printed blister foil

The color difference ΔE_{00} is defined as the color difference between unexposed prints and the exposed prints with time. It is observed in Fig. 5 that color difference is continuously increasing with time. Moreover, the visual analyses are performed by the ten observers to observe the visual color change. It has been observed that the color difference is continuously increasing with variation of time due to water immersion and water spray method and the visual results are similar to the experimental findings.

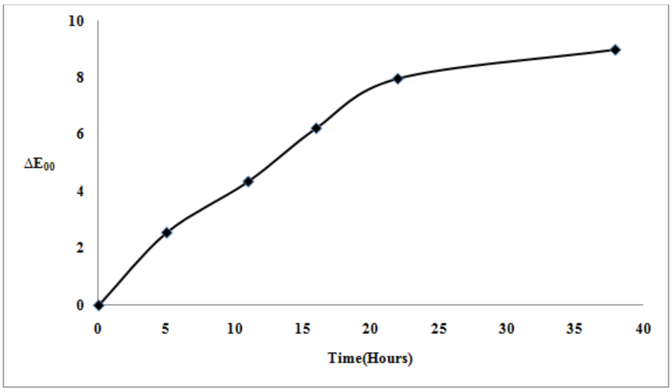

Fig. 5: Color difference of printed blister foil after exposing to water

B. Analysis of Kinetic model and Error Estimation

The fading behavior due to water exposure is described by the first order reaction kinetic analogy which is defined in Eq. 2. It predicts the watertfastness characteristics due to long time water exposure of food and medicine packages. R value in Eq. 2 is a physical parameter to determine the color degradation of magenta prints due to water exposure. The experimental data and predicted data by Kinetic model are plotted in Fig. 6.The waterfastness properties of prints is assessed by the estimated correlation coefficient which indicates a good agreement between estimated and experimental values. The correlation coefficient (R^2) for least square model of Magenta prints is 0.93.

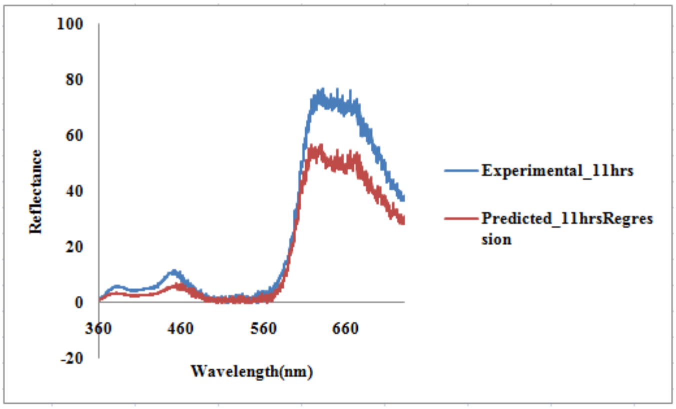

Fig. 6: Experimental Value Vs Predicted Value after 11 hours accelerated exposure by Regression model

C. Discussion

The waterfastness characteristics of prints are greatly influenced by the ink composition-specifically colorant-pigment or dye and media properties. In this present experiment, the used gravure foil ink is composed of the proper proportion of colorant, resin, solvent and additives. This magenta foil ink is formulated with the rhodamine dye. The conventional rhodamine dye has low fastness due to the presence of the chlorides or sulfates which are easily soluble not only in alcohols and glycols but also in water [18]. Therefore it may be recommended to add auxiliaries such as precipitants or resins which may improve the water fastness. Colorant must be chosen to resist these environmental factors so that there is the least effect on the print.

From the result, the color change after a certain period of exposure to water may be predicted by the kinetic model. It may be mentioned that the effect of humidity and temperature variation is assumed to be negligible as the temperature variation during the experiment was 20 ± 2° C and the humidity was 45 ±1%.

V. CONCLUSIONS

Based on the results it may be concluded that the kinetic model may help to assess the waterfastness characteristics of printed foil samples. Also the colorant must be selected to resist this kind of fastness properties so that there is the least effect on prints. The spectrum of magenta ink has been significantly changed with time due to fading.

Other primary colors may be examined in future work to verify the waterfastness properties of them with time. In further work, the relative importance of ink and media on the waterfastness of foil printing will be assessed to determine the permanence properties individually and then it will help to get another scientific approach to predict the print stability due to the effect of the ink media interaction. The fading characteristics with water with varying temperature and humidity may also be studied.

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