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Application of Artificial Neural Network to Predict the Light fastness of Prints on Paper

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Abstract

The purpose of this study is to describe the lightfastness of printed samples on the paper substrate due to long-time exposure by applying artificial neural networks. The lightfastness of prints is an important characteristic for determining their print stability. The fastness properties of prints are very important to check the print durability and image stability. It is the ability to retain the color strength of prints. It may be useful for verification of printed expiry date and authenticity or validity of the product. Nowadays, customers are very much influenced by good packaging and convinced to buy the products due to the displayed information. Packaging acts as a silent salesman and hence it is of immense importance for product manufacturers. Moreover, any kind of deterioration in package print quality will affect the product sale adversely. Little work has been done to study the fastness properties of gravure prints. In this work, paper printed in the gravure printing process has been taken as the sample as it has extensive usage in food, confectionery and medicine packaging etc. The paper samples are continuously exposed in artificial lightfastness tester BGD 865/A Bench Xenon Test Chamber (B-SUN) for assessing the light fastness of Cyan, Magenta, Yellow and Black ink on paper. The spectral curves and colorimetric values(L*, a*,b*) of prints are obtained by using ocean optics spectroradiometer (DH2000BAL) before and after exposure. An Artificial Neural Network model is proposed to predict the fading behavior of the prints. The optimal model gives excellent prediction with the minimal MSE for each color and a correlation coefficient of 0.98-0.99. As a comparison, a kinetic model is also employed. The results show that ANN has a higher prediction capability comparing to the kinetic model.

Keywords; *Artificial Neural Network(ANN), CIELab Data, Gravure Printing*

I. INTRODUCTION

Flexible package printing is drawing wider attention in the printing world. As this technology continues to rapidly progress into mainstream markets, many questions have been asked about the permanence of prints. Gravure printing is a traditional printing technology that is extensively used for flexible packaging because it is suitable to print on many kind packaging- substrates especially paper, paper board, film and foil etc. The lightfastness of prints is the ability of the print to retain its color strength and fading resistance upon exposure to light. Prints with poor lightfastness have a negative effect on sellers of various goods. In case of food, confectionary or medicine products that may require long stability so that the print surface does not change its color or fades away, as it may create confusion about the authenticity and freshness or validity of the product. On the other hand, it may be possible to check if a product is exposed to sunlight which is not supposed to be exposed (for example, medicines that have to be kept in dark and cool environment and whether the printed expiry dates are authentic).

The study of fading requires careful planning with regard to the operating conditions of the materials

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required for performance characteristics. Since the packages are stored in different indoor lighting conditions, there is a possibility of fading which may reduce their marketability. The durability of color quality plays an important role in the packaging when they are exposed to sunlight or any artificial light for a long period of time. The stability of the printed image is affected by light exposure, water, heat and different kinds of chemicals. This paper will focus only on the lightfastness which provides image stability of prints on paper. Nowadays paper is preferred as a substrate in food, confectionery and medicine packaging due to its reusability and eco-friendly properties. The temperature and relative humidity can affect the rates of fading. Different models may describe fading rates of print. It represents either a hypothetical mechanism or can be empirically derived during laboratory experiments.

A. Related Work

A lot of praiseworthy studies were carried out to discuss the effects of light on paper substrates, dyes, pigments, and photographs [1]-[7]. These studies explained whether the content of lignin has any significant effect on this phenomenon. The extensive utilization of densitometry or spectrophotometric measurements for the estimation of the degree of printed sample degradation is explained [8], [9]. H.Wilhelm and M. McCormick-Goodhart [10]-[12] discussed the image permanence studies for prints in detail, and also focused to analyze the effect of temperature, humidity, illumination, and air pollutants on the light stability. Reciprocity failure in high intensity accelerated light stability tests were also considered when making the display-life prediction. B.Rat et al. [13] examined the colorimetric properties of heat and moisture treated prints to ensure the information permanence under different illuminant conditions. Several studies explained the gradual decline of the gamut volume of prints to evaluate the effects of artificial weathering of prints. Therefore, the relative gamut volume change of prints on paper due to the influence of light might be expressed as a single number, thus conveniently quantifying the process of dye fading [14]-[17].

J. Izdebska et al. [18] and A. Borbély et al.[19] discussed the effect of artificial aging on the selected properties of flexible package printing materials so that one can select the proper substrate and inks on the basis of its lightfastness that is used in the flexible packaging industry. J. Lucas [20] proposed what types of tools can be used for testing lightfastness. Aydemir and Yenidogan discussed that the standard blue wool scale is used to characterize the light fastness properties of printed ink where the pigment selection is seemed to be an influencing factor on the lightfastness of printed material [21]. The color degradation was analyzed by applying the first-order kinetic model by Medley [22], Ahmed et al [23], and Mandal et al.[24]. O. Haillant [25] reported the photofading mechanism of colored materials where the photochemical behavior of organic or mineral colorant molecules and resin were examined due to exposure of real or artificial light conditions. It was also mentioned that chain scissions and reticulation reactions were generated through the photooxidation of the polymer matrix, which could influence the mechanical properties and cause appearance changes. Y. Shashoua et al. [26] discussed the effect of the natural and accelerated aging process on the cellulose nitrate to determine the lifetime of the adhesive. The colorimetric properties and UV/visible spectrums were evaluated to determine the effects of aging on the films.

Recently, an artificial neural network was developed to predict the light fastness of fabric samples. An artificial neural network model was designed to predict the Lab and wash fastness values of nylon by Balci et al. [27]. Many previous studies used a feed-forward neural network model to estimate an accurate reaction rate [28]-[31]. Few studies applied the ANN model to predict ΔE from the measured color coordinates of before and after dehydration

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process determining the color change of fruit or pumpkin [32, 33].

Though several studies focused on the lightfastness of paper substrate, most of the studies are on offset or digital prints. Little work has been done on the lightfastness of gravure printing. Considering the huge impact of fading on the marketability and authenticity of prints especially in food, confectionery and pharmaceutical packaging industry, the gravure printing process is chosen. In our previous work, the kinetic model and Artificial Neural Network (ANN) model is proposed to determine the fading behavior of prints on the foil and film substrate with time respectively [24,35]. In the current study, an Artificial Neural Network (ANN) model has been designed for the prediction of the fading behavior of prints on paper.

B. Objective

The goal of this study to evaluate the effect of light on prints produced by the gravure printing process on paper substrate.Lightfastness of a print is considered as the long-term permanence of the package of the item and maybe an indirect estimation of the expiry date of a product also. Some studies have applied the kinetic model to describe the color degradation of prints. Little work is done on predicting the fading behavior of prints by using the Artificial Neural Network model (ANN). So, the study has focused to assess the quality degradation of the print with time due to its exposure of light by designing an ANN model and to show the efficiency of the ANN model.

II. EXPERIMENTAL MATERIALS AND METHODS

Gravure printing is drawing wider attention in the packaging world because it is suitable to print on many kind packaging- substrates especially paper board, film, and foil, etc. It is the major printing process used for food, confectionery, cosmetic and pharmaceutical packaging due to its simplicity, quality, productivity and ability to print at very high speeds. Therefore, the experiment is carried out on the paper substrates which are printed by the gravure printing press. This printing unit comprises electronically engraved four color printing cylinders, blower, and heater. The prints are allowed to dry at 50°-60°C temperature. The experiment is performed on 100% solid patch of Cyan, Magenta, Yellow and Black inks of 152 lines per inch resolution. The printing speed is set at 60meter/min speed. The printing speed and pressure are kept constant during the printing of the samples. The ambient temperature and humidity are 17 ± 3°C and 35±5% inside the press. Multiple samples are tested for this experiment and the experiment is performed on five samples for each color patch to check the repeatability from each run. Samples are collected from five different runs.

A. Lightfastness Test

BGD 865/A Bench Xenon Test Chamber **(**B-SUN**)** **wa**s used for determining the lightfastness of prints. ASTM D3424-01standard, Test method 3 was followed to perform the test as per for evaluating the lightfastness of prints [37]. The artificial lightfastness testeris used for determining the lightfastness of paper prints. The test samples were cut at 150×70 mm sizes and positioned in the sample holders for the lightfastness test. The test samples were continuously exposed under the 1.8 KW accelerated xenon light source. The test prints were exposed in the artificial xenonchamber as per the ASTM G155 procedure.

The irradiance level on the print sample was 0.35 W/m^2. Nm (± 0.02 W/ m^2. nm) at 340 nm. The artificial lightfastness tester has a black panel thermometer consisting of a PT100 sensor and a metal panel painted by a black coating which is used to monitor temperature and humidity inside the chamber. The uninsulated black panel temperature was set at 55 ± 2°C and the relative humidity was set to 40±5%. The test was performed by exposing the test print samples for a different time interval. The samples were continuously exposed to xenon light

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tester up to a total of 170hrs under a controlled environment to support repeatability.

B. Measurement

The fresh test prints were taken for exposure in lightfastness tester and the reflectances of the samples were collected at regular intervals. All the data were measured on each test and reference sample prior to exposure and after each exposure. As per the ASTM D3424 standard, for visual estimation, the samples were kept in the viewing booth under the D50 light source. For instrumental evaluation, Ocean Optic Spectroradiometer (DH2000BAL) was used in the experiment with Tungsten Halogen and Deuterium light source. After print, the spectrophotometric curves and the L*, a* and b* values were measured using Ocean Optic Spectroradiometer. After each artificial light exposure, the spectrophotometric curves of the exposed samples at different time intervals were taken using an ocean optic spectroradiometer using 2° standard observer. For each sample, five readings were measured and the average of five readings was collected. Furthermore, the data collection process was completed at 17°C-23°C. In this experiment, initially spectral data and L, a, b data were collected first at 15 minute time interval for one hour. Then it was taken on an hourly basis till 24 hours. Then it was taken at 5 hours and later on at 10 hours interval till 160 hours. But after 160 hrs, the Magenta and Yellow color on the print samples did not remain. The data was repetitively taken for 5 runs. The five individual datasets were prepared for the proposed model so that the accuracy of the model may be checked.

The CIELab values were measured to determine the color changes of the unexposed and exposed prints shown in (1) and (2). The CIELabreprsents the lightness, L*, a value that is characterized by the lightness of prints; a* is a measure of the degree redness to greenness and b* is a measure of the degree yellowness to blueness. The changes in lightness and the shift in redness to greenness and yellowness and blueness were also observed. The a* and b* values are used to define the chroma of prints in (2). Then these coordinate values of color were applied to estimate the color differences (ΔE_{00}) of Cyan, Magenta, Yellow and Black prints using the unexposed and exposed sample's data at individual time interval [36]. These results are plotted to determine the correlation between color change as expressed in ΔE_{00} and time intervals.

$$\Delta L^* = L^*(t) - L^*(0) \quad (1)$$

$$C* = \sqrt{a*^2 + b*^2} \quad (2)$$

Where, L*(0)- the lightness of unexposed print, L*(t) represents the lightness after exposure with time t.

The differences in lightness, chroma and color difference are important parameters to describe the fading effect on prints.

III. THEORY

A. Overview of Artificial Neural Network

In this study, a feed-forward artificial neural network is preferred to develop the ANN model. Neural Network Toolbox of MATLAB (Mathwork, 2011) software is used to develop the proposed model [34,35]. In this proposed model, a multilayer feed-forward network has been applied for modeling to predict the light fastness behavior of prints over time. The schematic presentation of the proposed ANN network is shown in Fig. 1. The development of an artificial neural network model generally comprises three stages- preparation of the data for the training and then the training of the neural network with the selected data. Here, an objective function is applied to minimize the errors in predicted and target values. The final step is the testing in which the trained network is tested with the unknown dataset and consequently the accuracy in the predicted pattern is determined.

In this study, the artificial neural network (ANN) model is designed with three layers –the input layer,

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hidden layer and output layer shown in Fig. 1. The input layer consisted of two input parameters which were wavelength and different time intervals. This hidden layer is consisted of

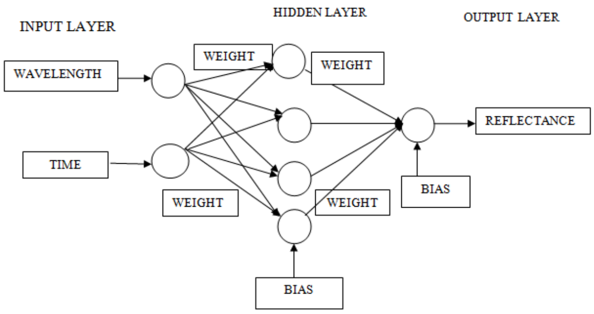

Fig. 1: Structure of feed-forward ANN

variable number of neurons. The output layer is consisted of one output parameter i.e. the reflectance value at different exposure time. In this ANN model, a hyperbolic tangent activation function defined in (3)and a pure linear function have been applied in the single hidden layer and in the output layer. The tangent transfer function is selected as the activation function defined in (4) due to lower calculated mean squared error values than the sigmoid function and a linear function [32].

$$tanh = \frac{e^x - e^{-x}}{e^x + e^{-x}} \quad (3)$$

$$MSE = \frac{1}{P}\sum_{p=1}^{P}\left(D_p - O_p\right)^2 \quad (4)$$

In order to avoid over-fitting and to get the best network, the training data set of the proposed ANN model was divided into three subsets including the training, cross-validation (CV) and test data set [33]. The 70% of the data in training set was used to train the network, and 15% of the data used as cross-validation which were applied to monitor the neural network performance during training and the test set included 15% of the data used to verify the accuracy of the network and compared the performances of various network structures. This proposed ANN model was trained with BackpropagationLevenberg-Marquardt (BP) algorithm to minimize the error during neural network training. In this model, 'trainlm' function is applied in the Matlab tool to train and test the ANN. The training procedure was continued until the minimum MSE of the validating sets was obtained. The trained sets were utilized to determine the fading behavior of different unknown times which were not previously fed to an artificial neural network. The evaluation of the performance of the ANN depended on MSE and the highest correlation coefficients between the experimental values versus predicted values (R^2). It helps to ensure the accuracy of the neural network to produce the outputs which are closer or equal to the experimental values.

In this study, the ANN model was tested twice for predicting the lightfastness of prints. Firstly, the proposed ANN model was trained up to 70hrs time data to predict the lightfastness of 120hrs and 150hrs. Then the model was trained up to 90hrs time data to predict the lightfastness of 120hrs and 150hrs. In the second case, 50 hours of data were not fed and it was also used for verification. The prediction for 150 hr data was shown only in Fig. 5 when the model was trained up to 90hrs time data. MSE and correlation coefficient R2 are also determined for this set. However, the data were available for 120hrs time data also. The values were more or less similar. So the study may claim that the ANN model works as a predictive model. In the second case, the model also predicted the lightfastness of 50hrs which might act as the behavioral model.

IV. RESULTS AND ANALYSIS

A. Spectral distribution of prints with time

Fig. 2 a), b), c) and d) represents the spectral reflectance of Cyan, Magenta, Yellow and Black prints done on the paper substrate. Fig. 2a) shows the spectral reflectance distribution of Cyan paper print in which the reflectance value of cyan print is increased in the blue zone with further exposure. The reflectance spectra of magenta ink printed on paper are plotted in Fig. 2 b) where it is found that the reflectance value is continuously increasing in

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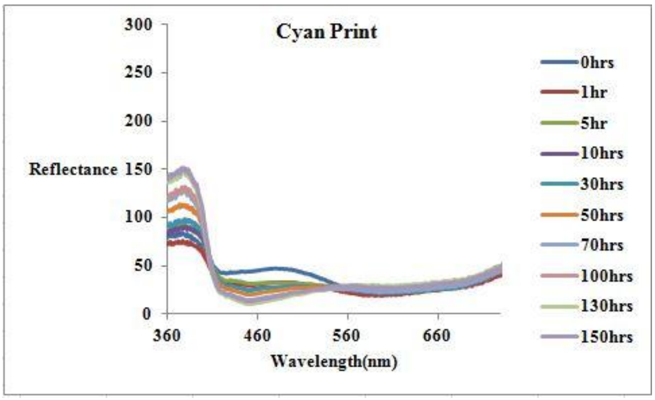
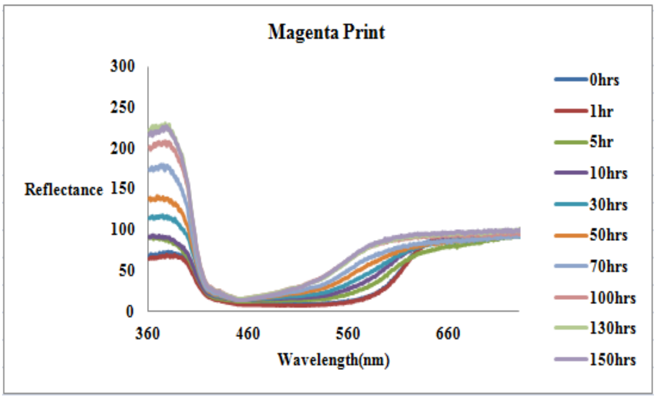
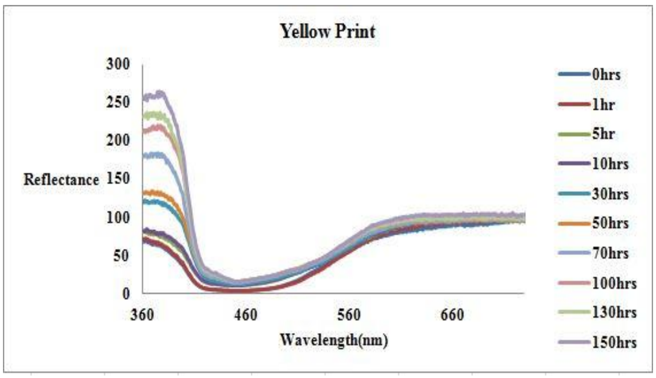
360nm-410nm and The reflectance value is also increased in the spectral range of 510nm-610nm zone with time. It is found in Fig. 2c) that the yellow ink on paper has shown variance in the spectral region 360–450nm. There are no significant changes in Black paper print which are plotted in Fig. 2d).



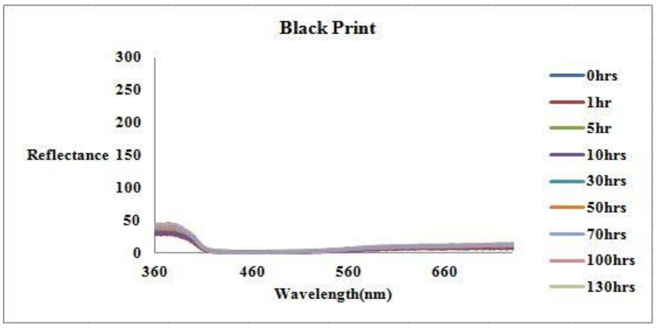
a)



b)



c)



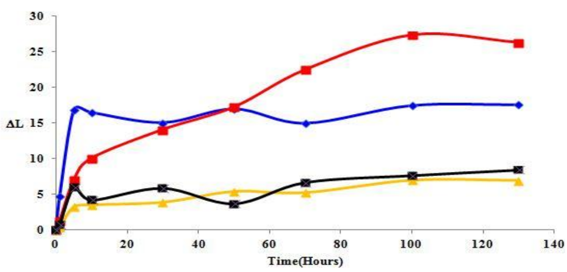
d)

Fig.2: Spectral data of fading on a) Cyan Print b) Magenta print c) Yellow print and d) Black print on the paper

B. Effect of Light exposure on Colorimetric Properties of Paper Prints

The variation of lightness L and chroma at different times are plotted for each color print paper substrate shown in Fig. 3a) and Fig. 3b) respectively. Fig.3a) shows that the ΔL value for Cyan print slightly decreased with time. The significant changes in ΔL value is shown in Magenta and Yellow print. The lightness values of Magenta print and Yellow print are gradually increased with time due to artificial light exposure. It clearly indicates the fading with time. In contrast, the ΔL value for Black Print is initially increased but then a little reduction is seen with time.

The change in chroma for the paper substrate is presented in fig. 3b) where a strong reduction in chroma is seen for Yellow and Magenta prints on a paper substrate which turns grayish. It is also seen that the differences in chroma for Cyan prints and Black prints are little increased during artificial xenon light exposure which turns slightly yellowish.



a)

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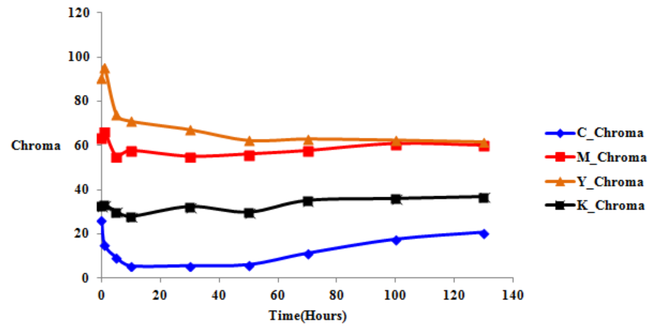
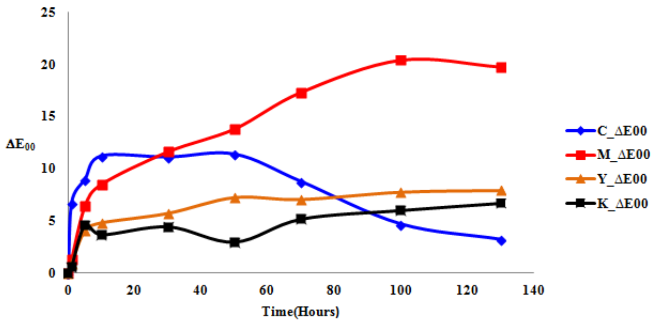


b)

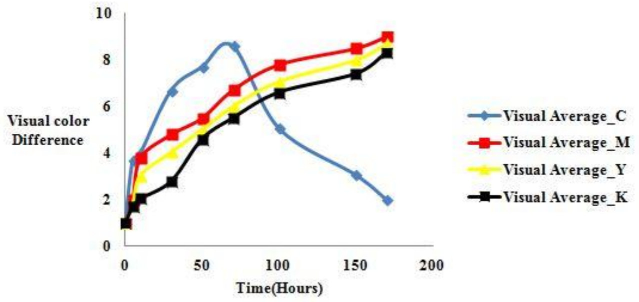
Fig. 3: Changes in a) L value b) Chroma of Cyan, Magenta, Yellow and Black print on Paper substrate after exposing to xenon light source

The color stability after the artificial lightfastnessThe color stability after the artificial lightfastness test can be monitored with the color difference ΔE_{00} and obtained results are shown in Fig.4a) It shows the overall color difference ΔE_{00} for each color prints on the paper substrate after artificial light exposure. The ΔE_{00} value for Magenta print in Fig.4 shows the faster fading. The greatest values are obtained for Magenta prints. Fig. 4 also shows a slight increase in Yellow and Black prints. The Cyan print on paper shows a faster increase at the beginning of exposure and then decreased with time.

Moreover, the color difference is also analyzed by visual observation of the fifteen observers for each color shown in Fig,4b). The findings is similar with the experimental results.



a)



b)

Fig. 4: a) Color difference b) Visual Color Difference of Cyan, Magenta, Yellow and Black print on Paper substrate after exposing to xenon light source

C. Comparison of ANN Model and Kinetic Model

In the present study, the optimum number of neurons in the hidden layer is chosen by trial/error method based on minimizing the difference between estimated ANN outputs and experimental values. After several repetitions, it is seen in Table 1 that the proposed ANN model with 10 neurons has produced minimum MSE for the prediction of lightfastness properties of prints. This ANN model is examined with 5 datasets to predict the repeatability of the fading behavior of print packages over time. The designed neural network model has been trained best with MSE value 0.2934, 0.5692, 0.6329 and 0.1456 for each color. The proposed ANN model for testing data has shown the best prediction accuracy illustrated in Fig. 5a), b), c) and d) for Cyan, Magenta, Yellow and Black prints, respectively, in which the comparison of the ANN output (predicted) data and the experimental data of the network trained with R2 0.99 for each color is shown. The calculated correlation coefficient values(R2) for estimation of lightfastness properties of Cyan, Magenta, Yellow and Black prints show a good agreement between predicted and experimental values. Therefore, the configuration of the ANN model including 10 neurons in the hidden layer is efficiently recommended for the prediction of lightfastness properties of prints with time.

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A regression model was also developed with the same data which were applied to the proposed ANN model training. The performances of both Kinetic and ANN modeling were analyzed based on the correlation of determination (R2) and mean square error (MSE).Fig. 3 also depicts the predicted reflectance for 150hours exposure applying the ANN model and regression. The result presents that the ANN model has higher modeling and prediction capability on the light fastness effect of prints due to fading than the kinetic model. The correlation coefficient for the least square model is very less for Cyan, Magenta, Yellow and Black respectively and the ANN model is 0.99 for Cyan, Magenta, Yellow and Black respectively.

Table I: ANN model performance for prediction of fading behavior of Cyan, Magenta, Yellow, and Black Print on Paper for different number of neurons in a hidden layer

Print	No. of Hidden neurons	MSE
Cyan	3	3.3198
	5	2.028
	7	1.0864
	10	**0.2934**
Magenta	3	3.7902
	5	2.3859
	7	0.9101
	10	**0.5692**
Yellow	3	2.6027
	5	1.3737
	7	1.1259
	10	**0.6329**
Black	3	0.2392
	5	0.1867
	7	0.1499
	10	**0.1456**

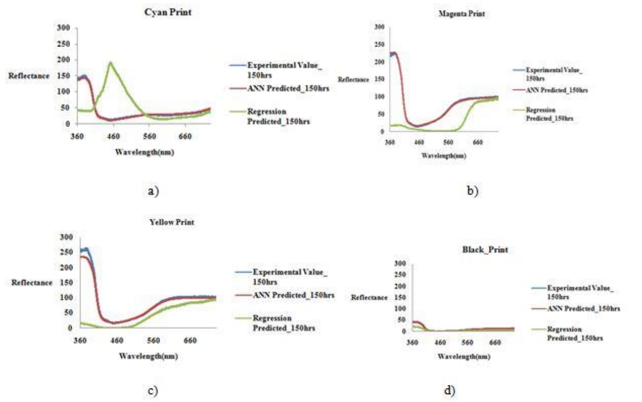

Figure 5: Experimental Value Vs Predicted Value after 150hours accelerated exposure by ANN model and Regression model for a) Cyan b) Magenta c) Yellow d) Black print on Paper

D. Discussion

The colorant molecules have a great influence on the lightfastness properties of prints. This study has focused on the lightfastness of paper prints which are printed by gravure inks. The gravure inks are formulated with pigment, resin, solvent, and additives [39]. During the artificial light exposure, not only the colorant molecules but also the resins undergo various chemical processes, which result in fading. Though the colorants and the resin affect each other during the artificial light exposure due to this chemical evolution but the effect of the ingredients cannot be investigated individually. The increase of b* value can be occurred due to the presence of chromophores which appear by the degradation of paper components such as cellulose, hemicellulose, and lignin during artificial light exposure [38]. A.M. Emsley and M. Ali[40] have reported that the discoloration of paper prints causes the degradation of cellulose. The presence of moisture, oxidative agents and microorganisms is playing important role in this process and especially the presence of acidic substances. Therefore, it is suggested that the printing substrate may be selected for printing that has low concentrations of heavy metals to achieve greater optical stability of paper prints because the photocatalytic activity and absorbency in UV area is characteristic for heavy metals, which lowers the brightness and increases

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the yellowness [38]. It is also discussed that short term irradiation of paper initiates light induced oxidation reactions, which continues even after the paper is stored in the dark [41]. The discoloration can be described by yellowing or browning to darkening, depending on the wavelength range of absorption [25]. It is stated by O. Haillant that the fading due to the influence of light may be defined as yellowing or photo-oxidation. In the present investigation, Fig. 3a) claims that the yellowing occurs for Cyan and Black prints. According to J.Lucas [20], the real fading problems in four-color process inks occur in Magenta and Yellow. Fig. 3also depicts that fading occurs in Magenta and Yellow prints due to oxidation which occurs due to the photochemical behavior of the compounds of the ink. It is stated that due to oxidative reaction the pigments or dye molecules get exited under oxidation process which results in the discoloration of prints [4] and [25]. O. Haillant has also reported that fluorescent colorants have poor lightfastness as these types of colorants typically undergo photooxidation from their first singlet excited state. In the present study, Magenta and Yellow prints claim the presence of fluorescence. The greatest color difference ΔE is achieved for Magenta print. Yellow prints present a slightly smaller color difference comparing to Magenta. The fading behavior of Magenta and Yellow prints may be described by the co-photooxidation of resin and pigments [25].

Based on the result, the color change after a certain period of exposure may be predicted by applying the Artificial Neural Network model. Hence the L* a*b* values of printed packages may help to predict the real age of a package. It may be applied for verification of printed expiry date and authenticity or validity of the product.

CONCLUSION

The current study was performed to predict the fading behavior of paper samples printed by the gravure printing process. Artificial Neural Network modeling was designed to predict the fading rate on printed samples. This study compared the performance of the ANN model and kinetic model for their prediction capabilities using the experimental values of spectral reflectance. The artificial Neural Network (ANN) model claims a better prediction of the fading rate than the regression model for each color.The three-layered ANN was designed with one hidden layer and the input layers representing two variables time and wavelength. On the basis of prediction outputs, it is possible to predict the lightfastness performance of prints. The most optimal ANN model was obtained with evaluative criteria (MSE and correlation coefficient R2). A very good correlation was revealed between the actual reflectance spectra and predicted reflectance spectra with high R2 and minimum MSE. These results may be used for verification of printed expiry date and authenticity or validity of the product.

The present study is done at controlled temperature and humidity inside the artificial xenon light chamber. So, the future study will be performed to examine the impact of temperature and humidity on the degradation of Cyan, Magenta, Yellow and Black prints on foil by varying those parameters and then it will guide to develop an artificial neural network model to predict the color stability due to the effect of temperature and humidity.

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CONFLICT OF INTEREST

The authors have no conflicts of interest to declare.

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