The absorption properties of reactive dyes on nylon fibers : statistical experiments and empirical modeling

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1. Introduction

The presence of terminal amino end groups in nylon substrates imparts substantivity towards anionic dyes, specifically acid dyes, direct dyes and reactive dyes[1,2]. However, colorations or dyeings on nylon materials using these dyes suffer color loss during laundering with the result that the vagrant dye is able to stain adjacent materials.

Phthalocyanine reactive dyes used in this study having reactive group react chemically with amino groups within the nylon substrates to form covalent bonds. Theoretically, by virtue of the covalent nature of the dye-nylon fiber bond, reactive dyeings on nylon substrates can display excellent wet treatment fastness without any recourse to an aftertreatment. Thus, the aim of this work was to examine the exhaustion property of phthalocyanines dye based on the C. I. Reactive Blue 21[3] with nylon substrates using statistically designed experiments[4]. Optimum exhaustion (%E) and fixation (%F) were determined. In addition to this, statistical analysis of the data and model equation, a relatively new study in the dyeing process, was carried out for the experimental data to assess the quality of the model.

2. Experimental and model development

Experiments were designed using Statistical Experimental Design[4] by MINITAB 14 (PA, USA). Experiments were carried out in a laboratory-scale infra red dyeing machine (ACE-6000T) by varying pH, temperature, concentration on level of dye exhaustion and fixation and (%). The results of experimental design were studied and interpreted by MINITAB 14 (PA, USA) statistical software to estimate the response of the dependent variable (% exhaustion and % fixation).

Using the date, empirical model was developed. The behaviour of the system was explained by the following empirical model[5]:

$$Y = \beta_0 + \sum \beta_i x_i + \sum \beta_{ii} x_i^2 + \sum \beta_{ij} x_i x_j \quad (1)$$

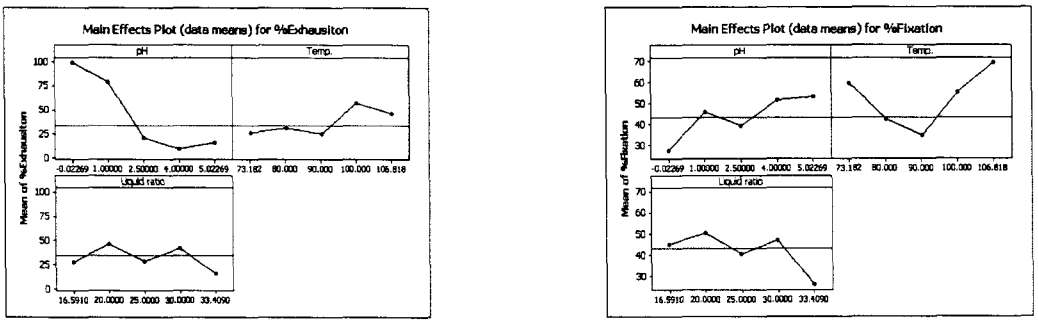
Where, Y is the dependent variable, β are the regression coefficients, x are independent data. RMSE (Root Mean Square Error) is the important tool to validate the model equation for its prediction capacity and was calculated using the following formula[5],

$$\text{RMSE} = \sqrt{\frac{\sum_0^N (\text{Exp.} - \text{Pred.})^2}{N}} \quad (2)$$

Where, Exp. is the experimental value, Pred. is the predicted value from model equations and N is the total number of experiments. Statistical analysis of the experimental data was performed. The quality of the fit of the polynomial model equation was expressed by the coefficient of determination R^2.

3. Results and discussions

The experimental results show that high pH (pH 1), high temperature (100°C) and low liquid ratio (20:1) leads to high exhaustion for phthalocyanine reactive dye.



(a) (b)

Fig 1. Effect of variables on for reactive dye on Nylon 6, 6 : (a) % exhaustion, (b) fixation.

Using the experimental results, a polynomial equations((3) & (4)) were developed.

$$Y = 0.899056 - 1.6035 X_1 + 0.31477 X_2 + 0.64409 X_3 + 0.00289 (X_1X_2) + 0.00864 (X_1X_3) + 0.00596 (X_2X_3) - 0.00362 (X_1X_1) - 0.02398 (X_2X_2) - 0.00018 (X_3X_3) \quad R^2=0.9915 \quad (3)$$

Polynomial regression equation for % exhaustion of reactive dyeing of conventional cotton

$$Y = 0.9797 + 0.021823 X_1 + 0.778136 X_2 - 0.918031 X_3 - 0.0051262 (X_1X_2) + 0.00524 (X_1X_3) + 0.01470 (X_2X_3) - 0.004797 (X_1X_1) + 0.01457 (X_2X_2) + 0.063965 (X_3X_3) \quad R^2=0.9935 \quad (4)$$

The significance of the mathematical model developed was ascertained using Microsoft Excel regression (solver) analysis module. The results show (Fig.2) that the second-order polynomial model (Equations 3 and 4) was highly

significant and adequate to represent the actual relationship between the response (% exhaustion and fixation) and the variables, with very high coefficient of determination (R^2 = 0.9915 for % exhaustion and R^2 = 0.9935 for % fixation). This implies that 99.15% and 99.35% of the sample variation for % exhaustion and % fixation are explained by the independent variables and this also means that the model did not explain only about 0.04% and 0.11% of sample variation for % exhaustion and fixation respectively.

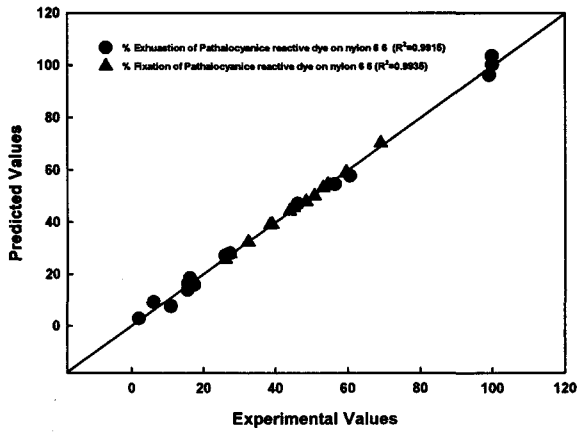


Fig 2. Experimental and Predicted values for % exhaustion and fixation.

4. Conclusions

Nylon substrates were successfully treated with phthalocyanine reactive dye using statistical experimental design and the main effect of variables were studied. An appropriate empirical model was developed to predict the behaviour of the process using excel solver functions and very high correlation coefficient was obtained. The statistical significance of the model equations were thoroughly analyzed and discussed.

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