Mathematical Modelling of Colour Yield for Single Step Fixation of MCT Reactive Dye Printing and Crease Resistance Finishing of Cotton Fabric

Fareha Asim[1,*], Muzzaffar Mahmood[2]

[1]Department of Textile Engineering, NED University of Engineering & Technology Karachi, Pakistan
[2]Department of Mechanical Engineering, NED University of Engineering & Technology Karachi, Pakistan

Abstract   Statistical analysis and mathematical modelling can play a vital role in understanding the factors affecting the single step fixation process of reactive printing and crease resistance finishing. The aim of this study was to model colour yield in single step fixation process of cotton fabric, as a function of hue, chroma, concentration of crease resistant and fixation temperature. The statistical analysis of the influential factors revealed the quadratic effect of each factor on the colour yield of in single step fixation process. The fitted regression equation of colour yield modelled the relationship of each factor on the in single step fixation process. The high values of coefficient of determination implied that the model effectively explained the process.

Keywords   Crease Resistance Finishing, Colour Yield, Mathematical Modelling, Regression Equation, Reactive Printing

1. Introduction

Statistical methods[1-6] are widely used in textiles to analyse and optimize the data so that results and conclusions are objective rather than judgmental in nature. Simple graphical methods play an important role in data analysis and interpretation. It is also usually very helpful to present the results of many experiments in terms of an empirical model, that is, an equation derived from the data that expresses the relationship between the response and the important design factors. Different statistical techniques[7-12] have been reviewed including ANOVA, response surface methodology and desirability function. The factors affecting the single step fixation of reactive printing and crease resistance finishing has been reviewed previously[13-16]. The four different factors namely A: hue, B & C: concentration of dye & crease resistant and D: fixation temperature are statistically analysed in this work. The proposed research work intended to develop the mathematical model of colour yield for single step fixation process of reactive printing and crease resistance finishing process. The experiments have been conducted in random order. The results were analysed using software Design Expert 8.0.

2. Experimental

* Corresponding author:
fareha@neduet.edu.pk (Fareha Asim)
Published online at http://journal.sapub.org/statistics

2.1. Process Route

The one step fixation of MCT reactive dye and crease resistance finishing is carried out as follows: In the first step ready to print fabric was padded with the crease resistant finish liquor, and then squeezed to obtain a 70% wet pickup. The fabric was then dried at 100°C for 1 min. The dried fabric was printed by the lab scale Rotary Printing machine (Zimmer). The finish-print fabric was simultaneously fixed using Econtrol method at 135°C for 5 minutes. The fixed samples were finally washed with non-ionic detergent until all unreacted dyes and chemicals were removed from the fabric surface.

2.2. Evaluation of Colour Yield (K/S)

Shade depth values were assessed and expressed in terms of the Kubelka-Munk (K/S) relationshipThe samples processed with simultaneous fixation were compared with those produced from a conventional process of reactive printing and Crease resistance finishing.

2.3. Statistical Analysis of the Data

After processing the experimental trials, K/S values were measured using spectrophotometer.The results obtained from the different experimental sets are presented in Table 1.TheK/S values were statistically analysed. Residual analysis and model adequacy checking were performed.

2.4. Model Adequacy Checking

2.4.1. The Normality Assumption

The normal probability plot of the residual for colour yield has been shown in from Figure 1. There is no severe indication of non-normality, nor is there any evidence pointing to possible outliers and the equality of variance assumption does not seem to be violated.
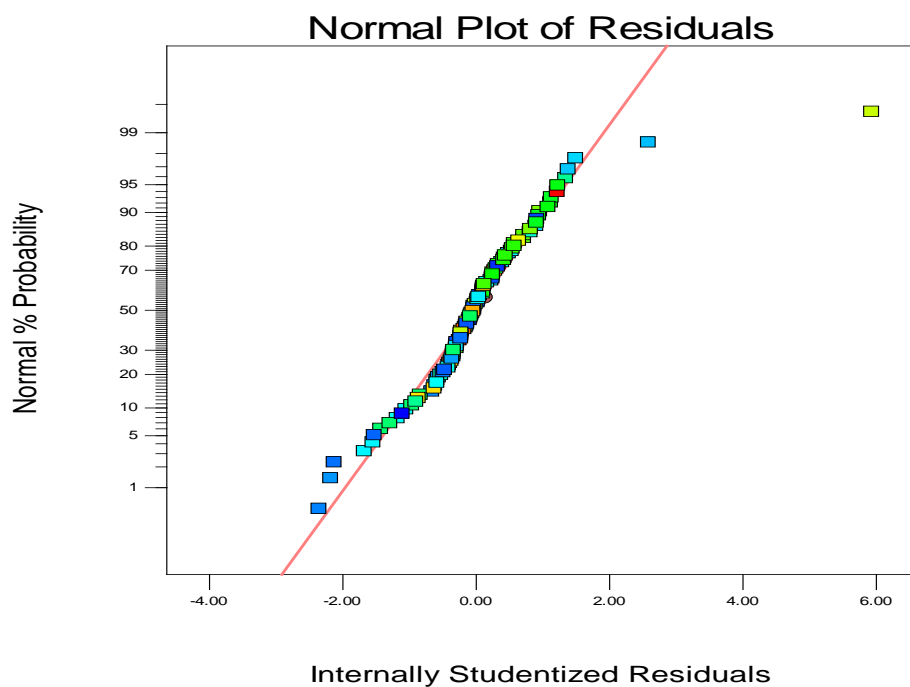

Figure 1.   Normal plot of residuals for K/S

2.4.2. Residual Analysis

Residual plots of colour yield have been shown from Figure 2and 3. The residuals are normally distributed and the equality of variance does not seem to be violated.

Figure 2.   Residual vs. run number for K/S

Figure 3. Residual vs. predicted plot for K/S

2.5. Analysis of Variances (ANOVA)

Table 1 shows the ANOVA results of the colour yield for single step fixation process of reactive printing and crease resistance finishing. The model p-value implied that the respective model is significant for colour yield. As can be seen in Table 1, the "lack of fit p-value" of colour yield implies that the lack of fit is not significant relative to the pure error, indicating that the suggested models are well-fitted to the observed response. The "Pred R-Squared" values of colour yield is in reasonable agreement with the "Adj R-Squared", indicating the model is adequate.
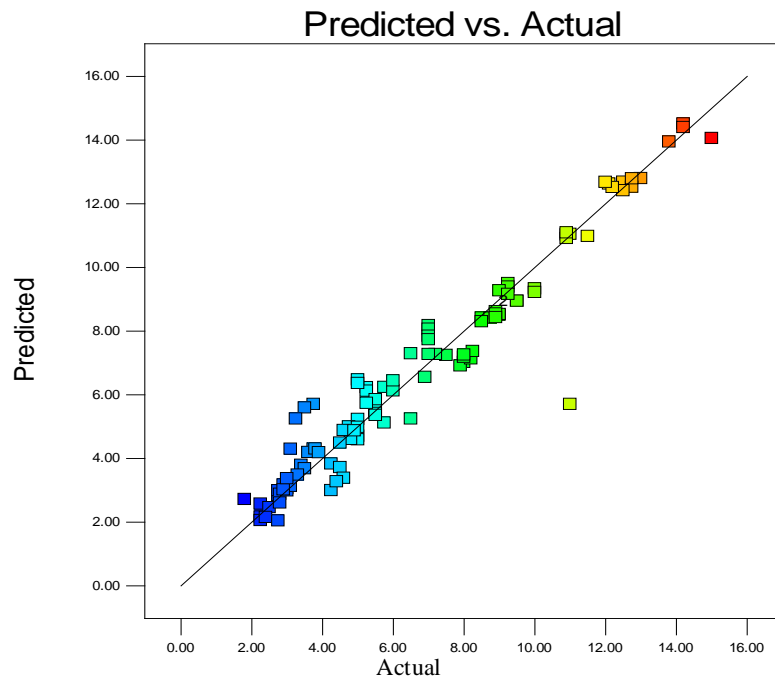
Table 1. ANOVA for colour yield (K/S)

Source	Sum of Squares	Degree of freedom	Mean Square	F-value	p-value
Block	0.91	1	0.91		
Model	1136.06	39	29.13	26.39	< 0.0001
A-Chroma	150.52	1	150.52	136.38	< 0.0001
B-Concentration Of CR	11.47	1	11.47	10.40	0.0020
D-Fixation Temperature	7.65	1	7.65	6.93	0.0105
CD	14.53	1	14.53	13.16	0.0006
A^2	10.35	1	10.35	9.37	0.0032
B^2	27.03	1	27.03	24.49	< 0.0001
D^2	7.03	1	7.03	6.37	0.0140
ABC	10.55	1	10.55	9.56	0.0029
ABD	5.63	1	5.63	5.10	0.0272
ACD	42.96	1	42.96	38.93	< 0.0001
BCD	6.73	1	6.73	6.10	0.0161
A^2D	7.75	1	7.75	7.02	0.0100
B^2D	4.68	1	4.68	4.24	0.0434
A^2B^2	8.73	1	8.73	7.91	0.0064
A^2D^2	7.64	1	7.64	6.92	0.0105
AB^2D	4.55	1	4.55	4.12	0.0463
ABD^2	4.73	1	4.73	4.29	0.0422
Residual	73.95	67	1.10		
Lack of Fit	42.36	62	0.68	0.11	1.0000
Pure Error	31.58	5	6.32		
Cor Total	1210.92	107			
Std. Dev.	1.05	C.V. %	15.72	PRESS	190.20
R^2	0.9389	Adj R^2	0.9033	PredR^2	0.8428

Table 2. Alias structures for K/S

S.No.	Aliases
1	$[A] = A^3$
2	$[B] = B^3$
3	$[D] = D^3$
4	$[AB] = A^3B = AB^3$
5	$[AC] = A^3C$
6	$[AD] = A^3D = AD^3$
7	$[BC] = B^3C$
8	$[BD] = B^3D = BD^3$
9	$[CD] = CD^3$
10	$[A^2] = A^4$
11	$[B^2] = B^4$
12	$[D^2] = D^4$

Design-Expert® Software
k/s

Color points by value of
k/s:

15
1.8

Figure 4. The predicted vs. actual plot for K/S

The actual and predicted plot of colour yield has been shown in Figure 4. The actual values are the measured response data for particular run and the predicted values are the results generated using the approximate functions. It is found that the adequate precision of responses which measured the signal to noise ratio is much greater than 4, (Table 1). This indicates the models are adequate to be used to navigate the design space.

Focusing on the model maximizing the "Adjusted R-squared" and the "Predicted R-squared" different process order selection has been made for colour yield. The alias structures of the colour yield are shown in   Table 2.

3. Results and Discussion

3.1. Analysis of Colour Yield (K/S)

The quartic model has been selected for the response variable K/S. The detail of ANOVA of K/S is shown in Table 1. The Model p-value less than 0.05 implies the model is significant. In this case A, B, D, CD, A^2, B^2, D^2, ABC, ABD, ACD, BCD, A^2D, B^2D, A^2B^2, A^2D^2, AB^2D, ABD^2 are significant model terms.   The "Lack of Fit p-value" of 1.000 implies the Lack of Fit is not significant relative to the pure error. The "Pred R-Squared" of 0.8428 is in reasonable agreement with the "Adj R-Squared" of 0.9033. Adequate Precision of 19.263 indicates an adequate signal.   The graphs of significant model terms for K/S have been shown from Figure 5 to 16. The graphs of significant model terms clearly lillustrate that the colour yieldof the CPF process is dependent on the interaction and curvature effect of chroma, concentration of CR and fixation temperature. The interaction of fixation temperature and fixation mode (Figure 8) noticeably show that the Econtrol process of fixation at 130-135°C will be efficient for the combined fixation of reactive printing and crease resistance finishing in terms of K/S. The methamatical model of colour yield has been shown in Equation (1). However, the fitted regression equation has been presented , Equation (2).

3.2. Model with Significant Variables at α = 0.05

$$K/S = 6.98 + 3.16A - 0.98B + 0.85C - 0.13D - 0.47AB + 0.56AC - 0.26AD + 0.57BC - 0.33BD - 1.03CD - 0.10A^2 + 0.93B^2 - 0.17D^2 \tag{1}$$
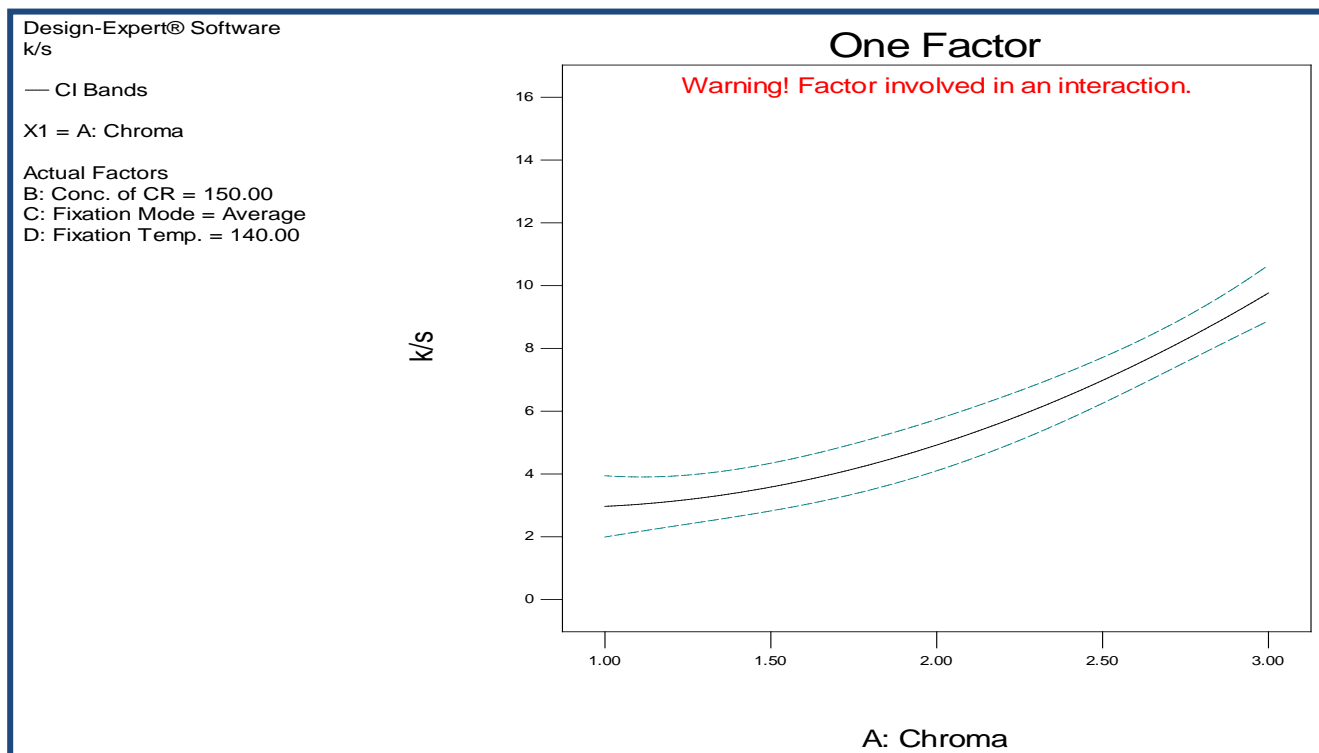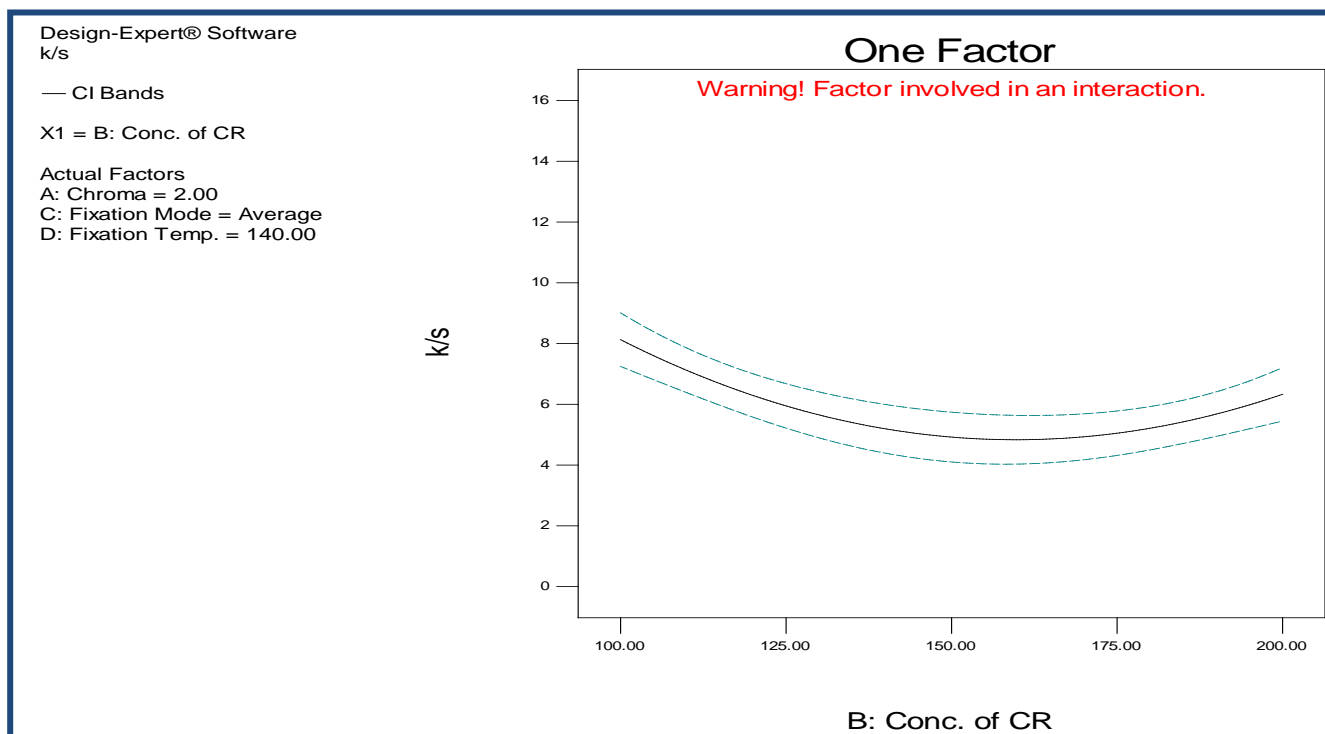
Figure 5. Effect of A on K/S
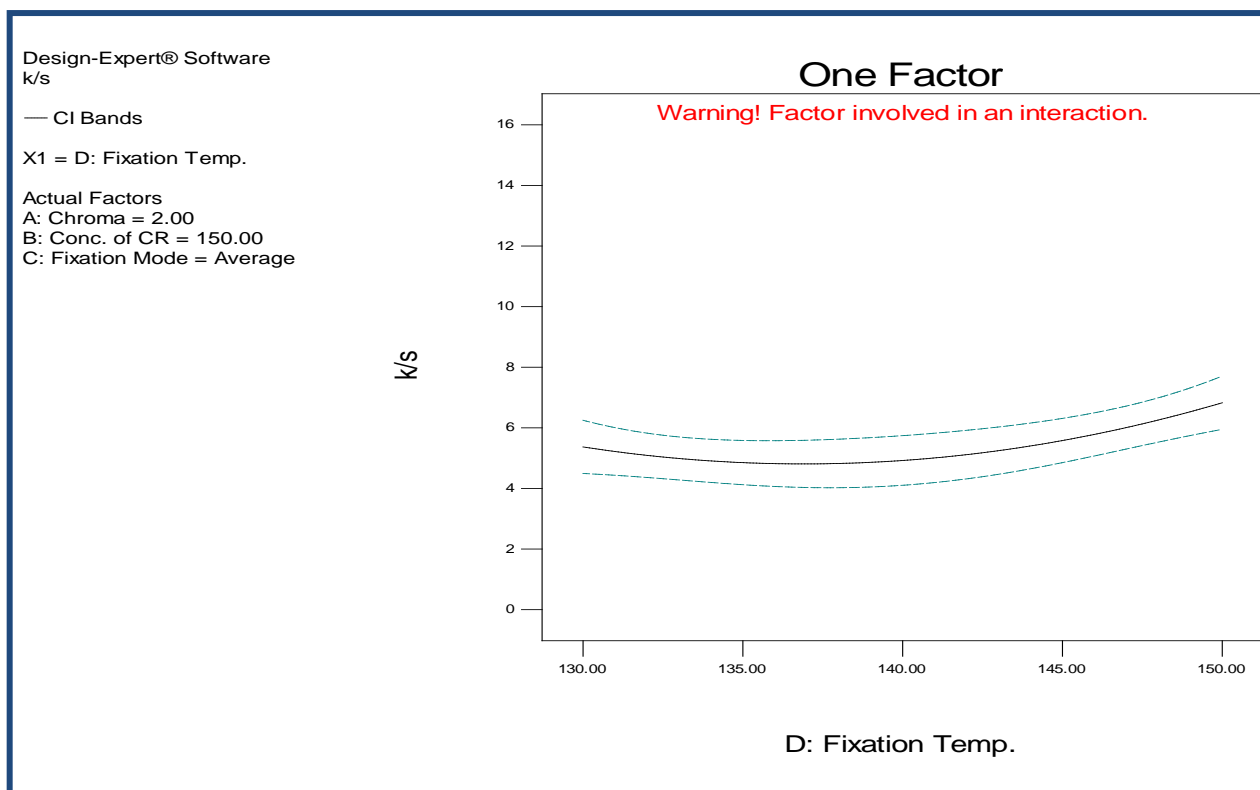
Figure 6. Effect of B on K/S
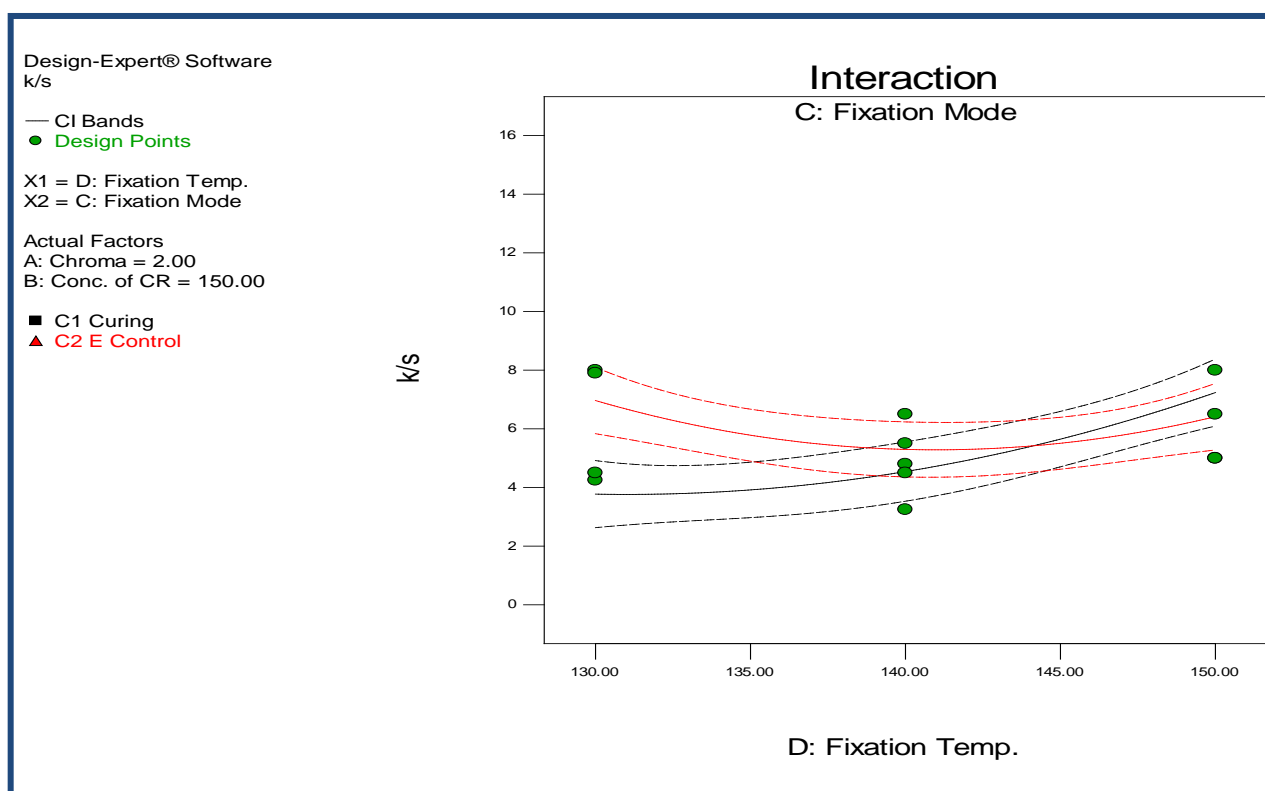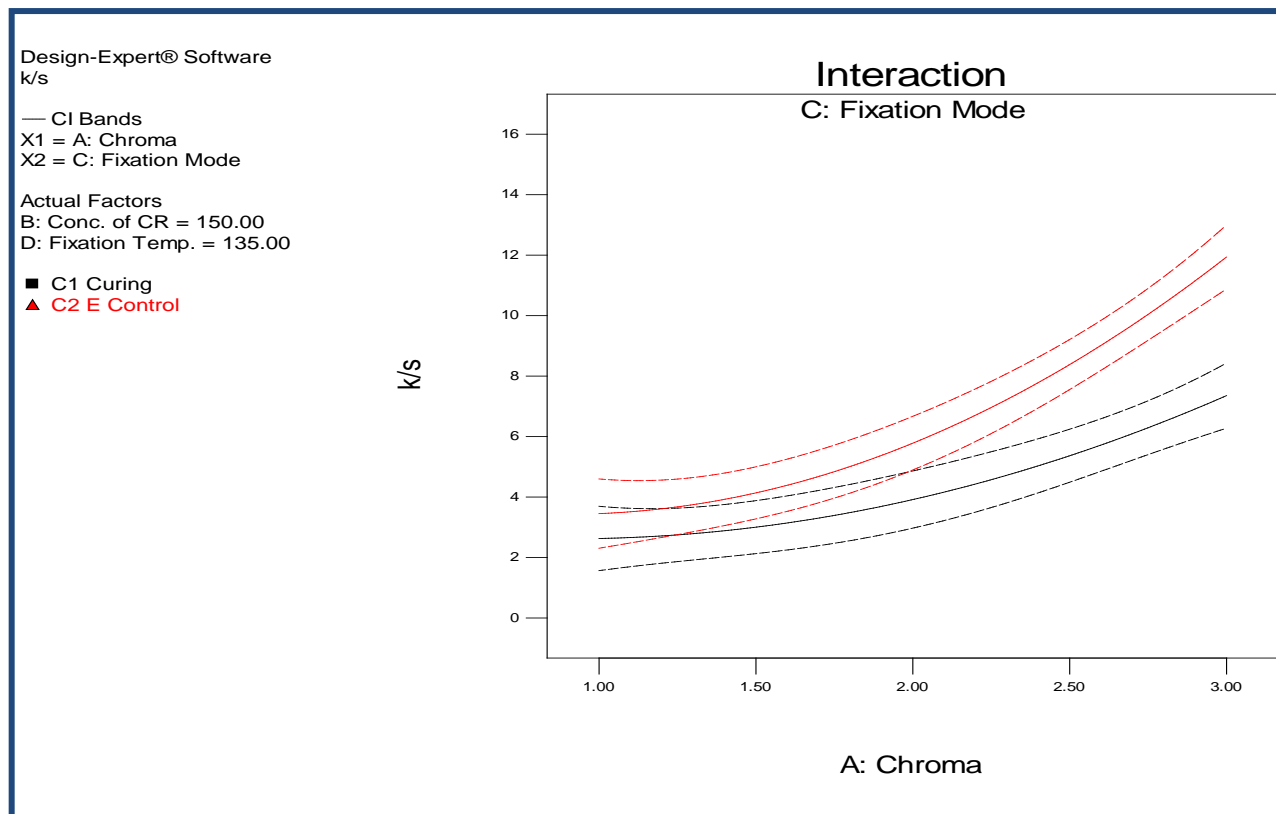
Figure 7. Effect of D on K/S

Figure 8. Interaction plot of CD with respect to K/S

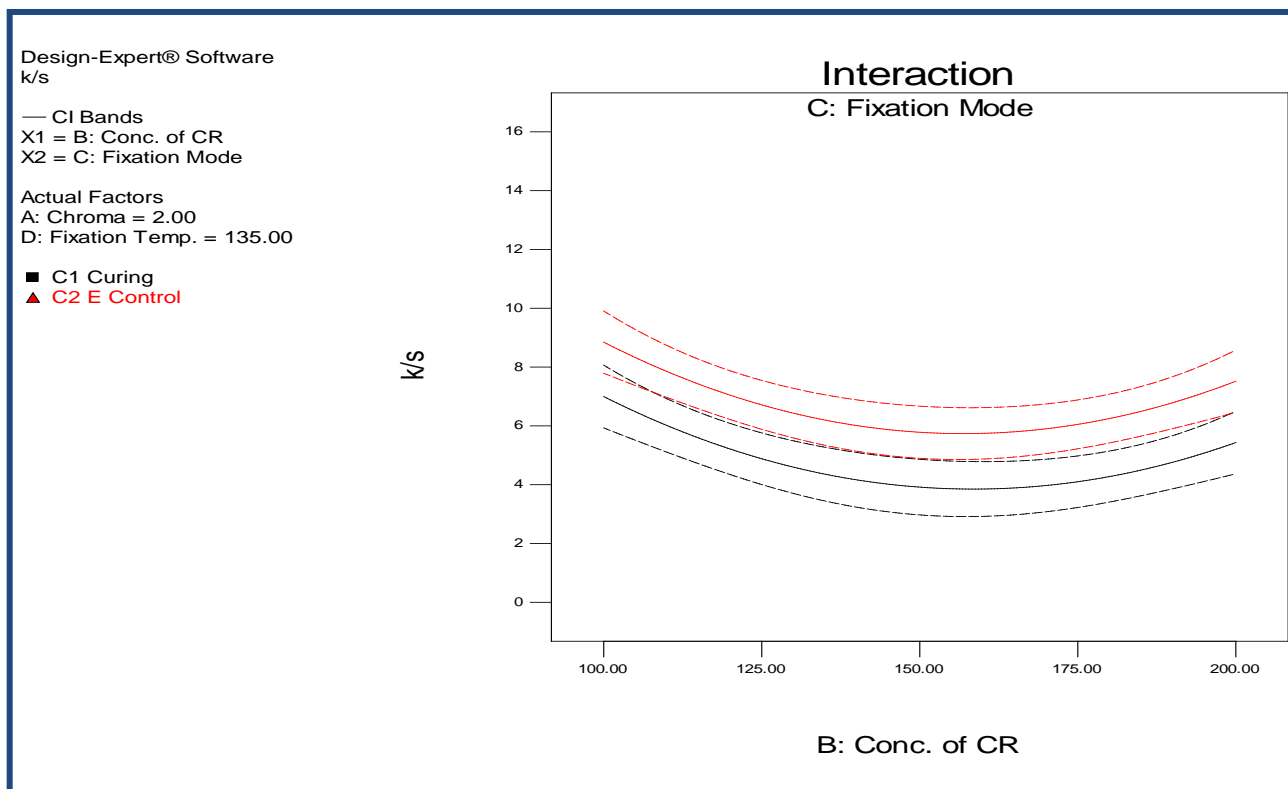**Figure 9.** Interaction plot of AC with respect to K/S

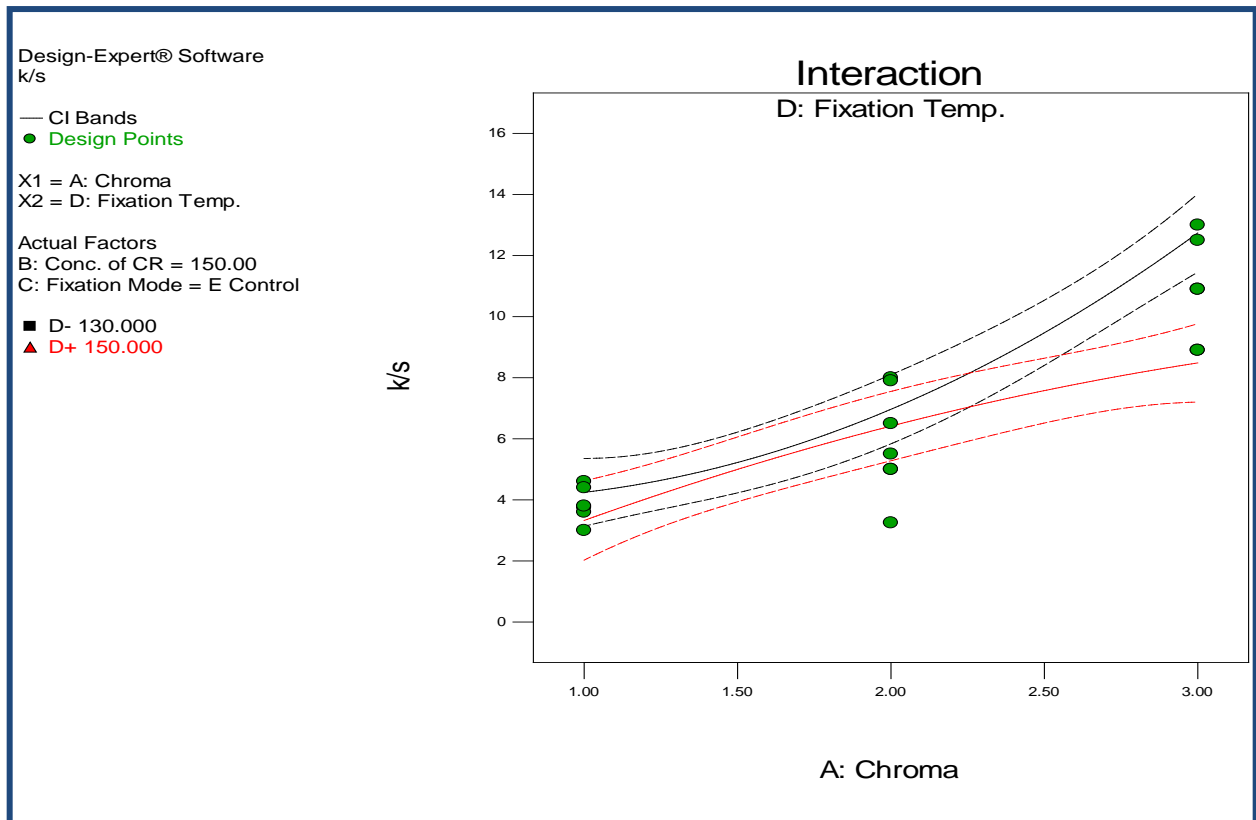**Figure 10.** Interaction plot of BC with respect to K/S

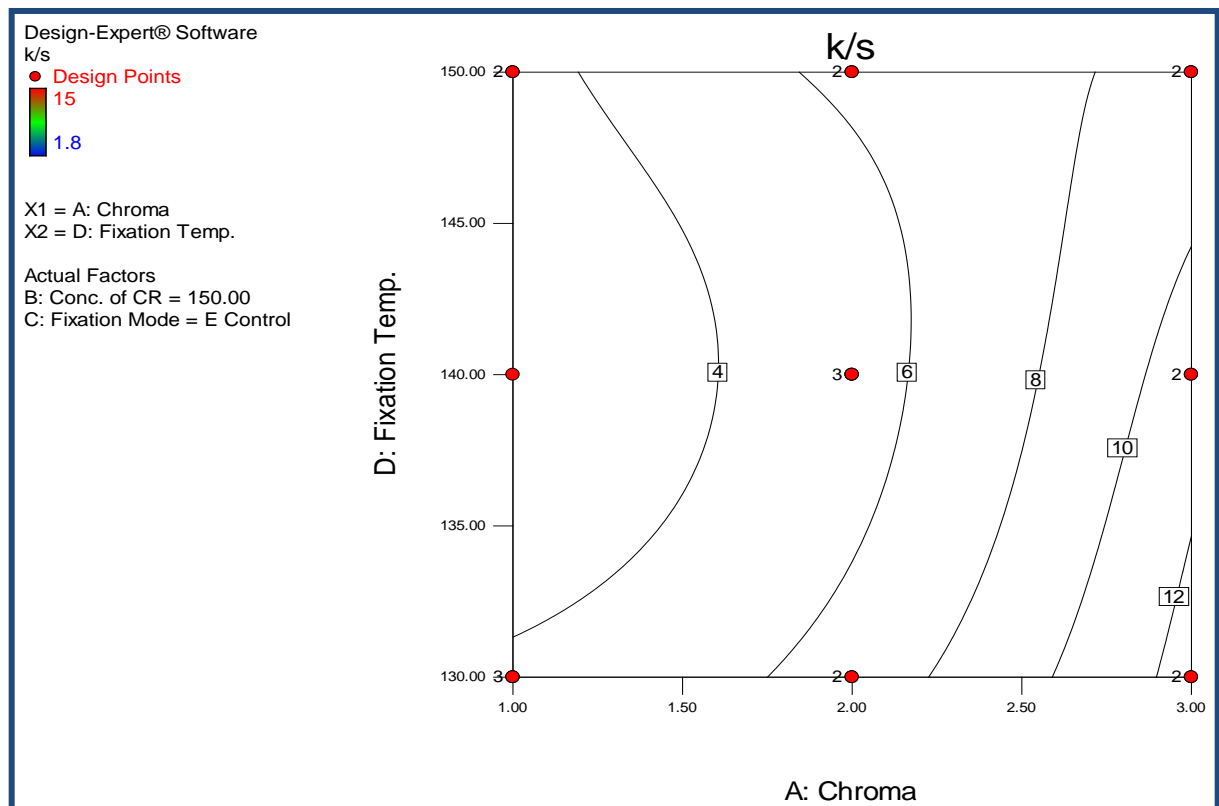**Figure 11.** Interaction plot of AD with respect to K/S

Figure 12. Contour plot representing K/S versus chroma and fixation temperature
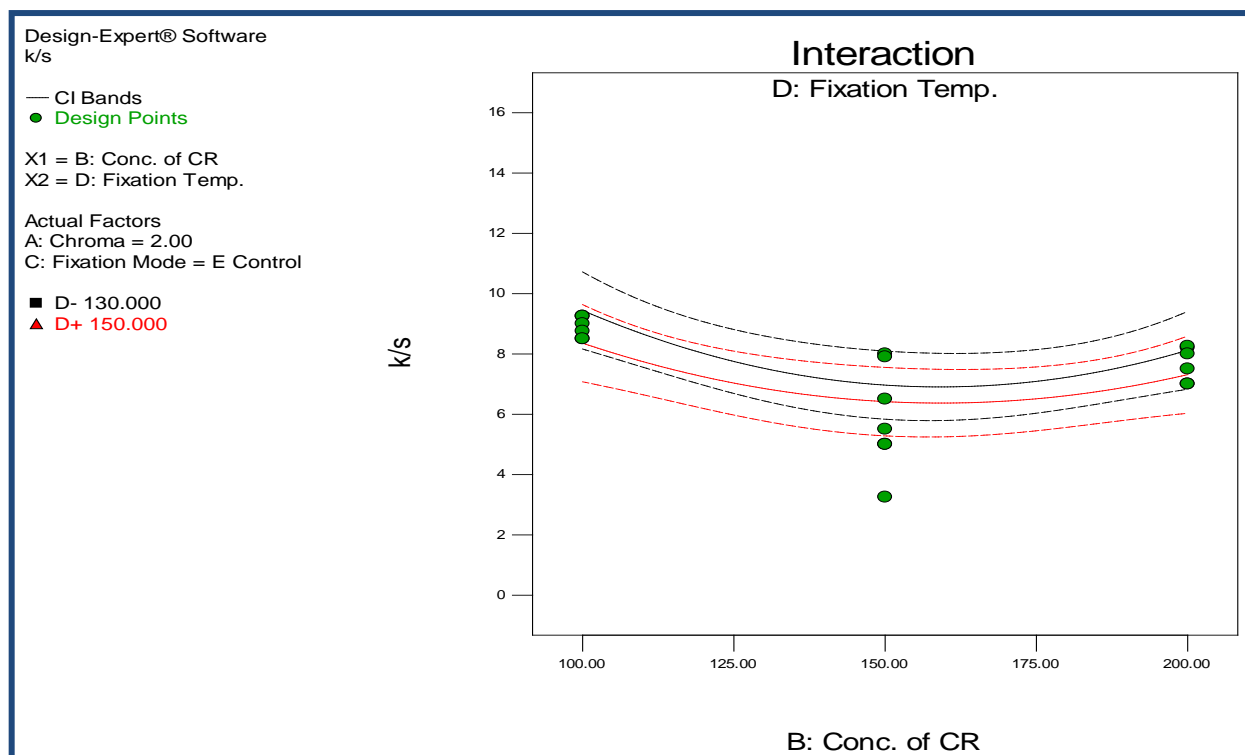
Figure 13.   Interaction plot of BD with respect to K/S
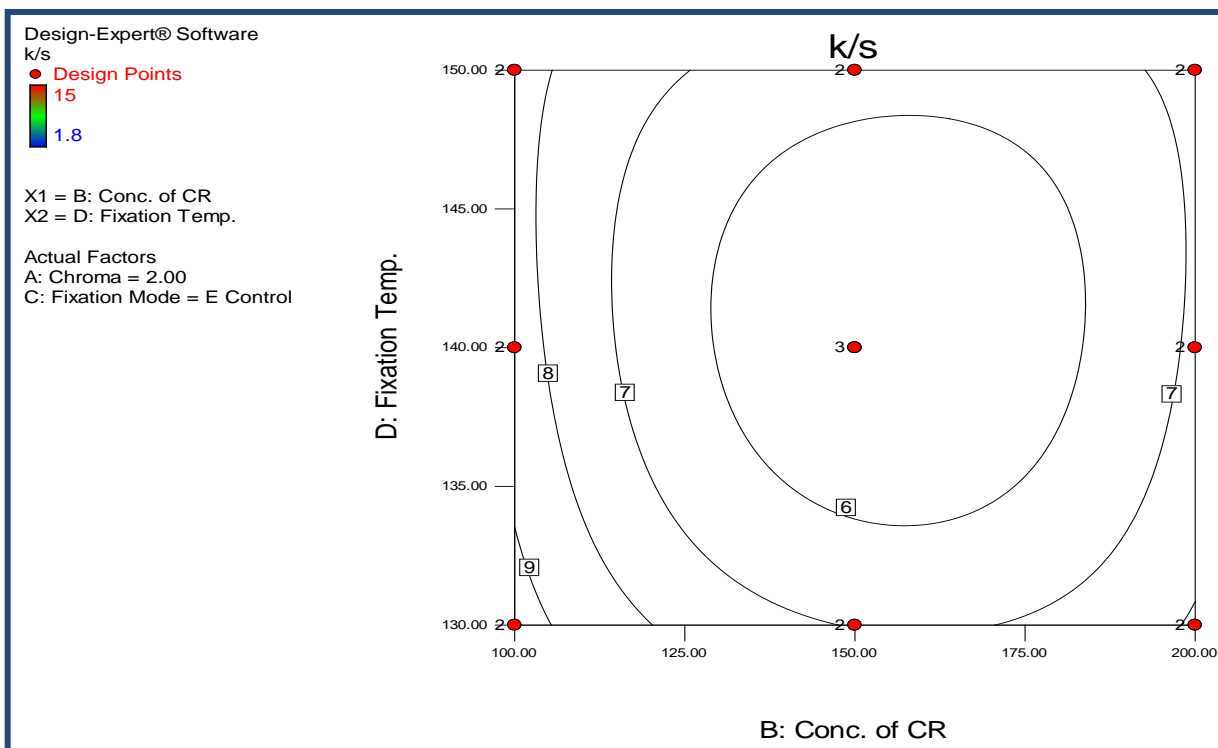

Figure 14.   Contour plot representing K/S versus concentration of CR and fixation temperature
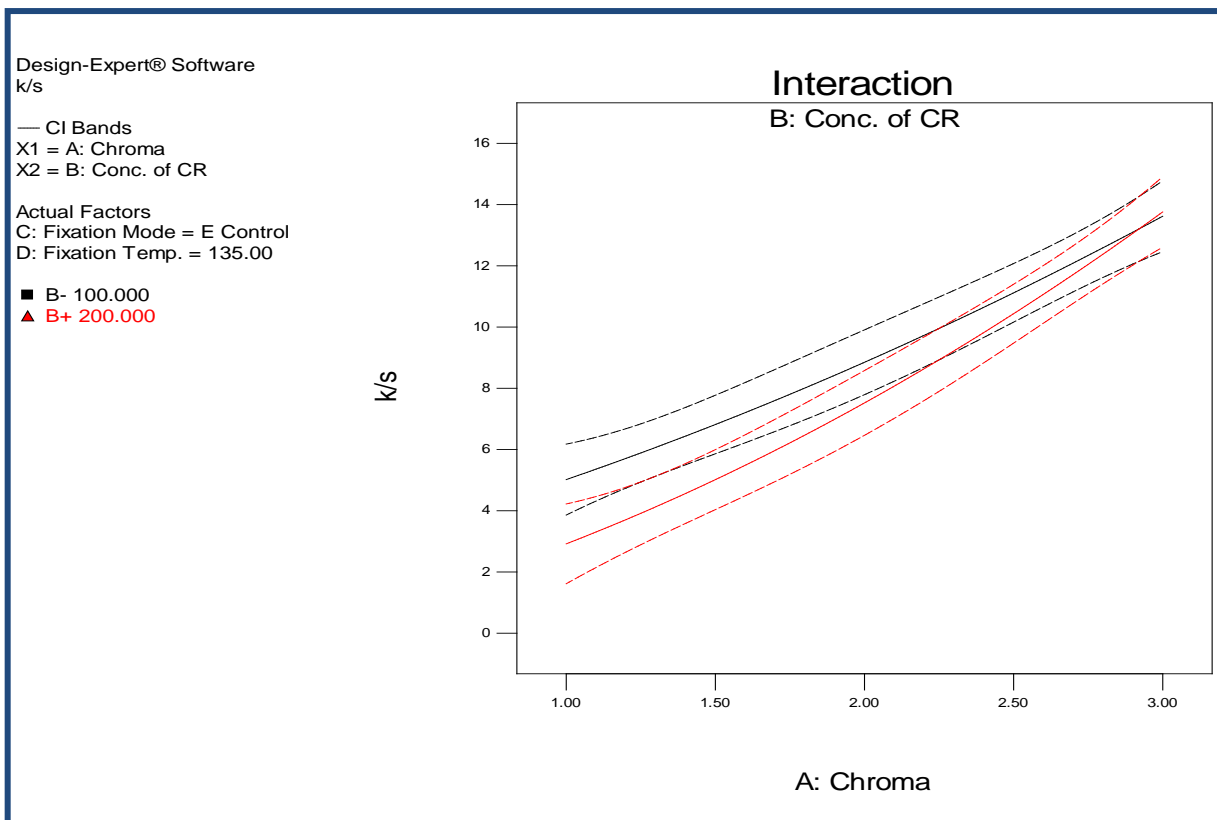
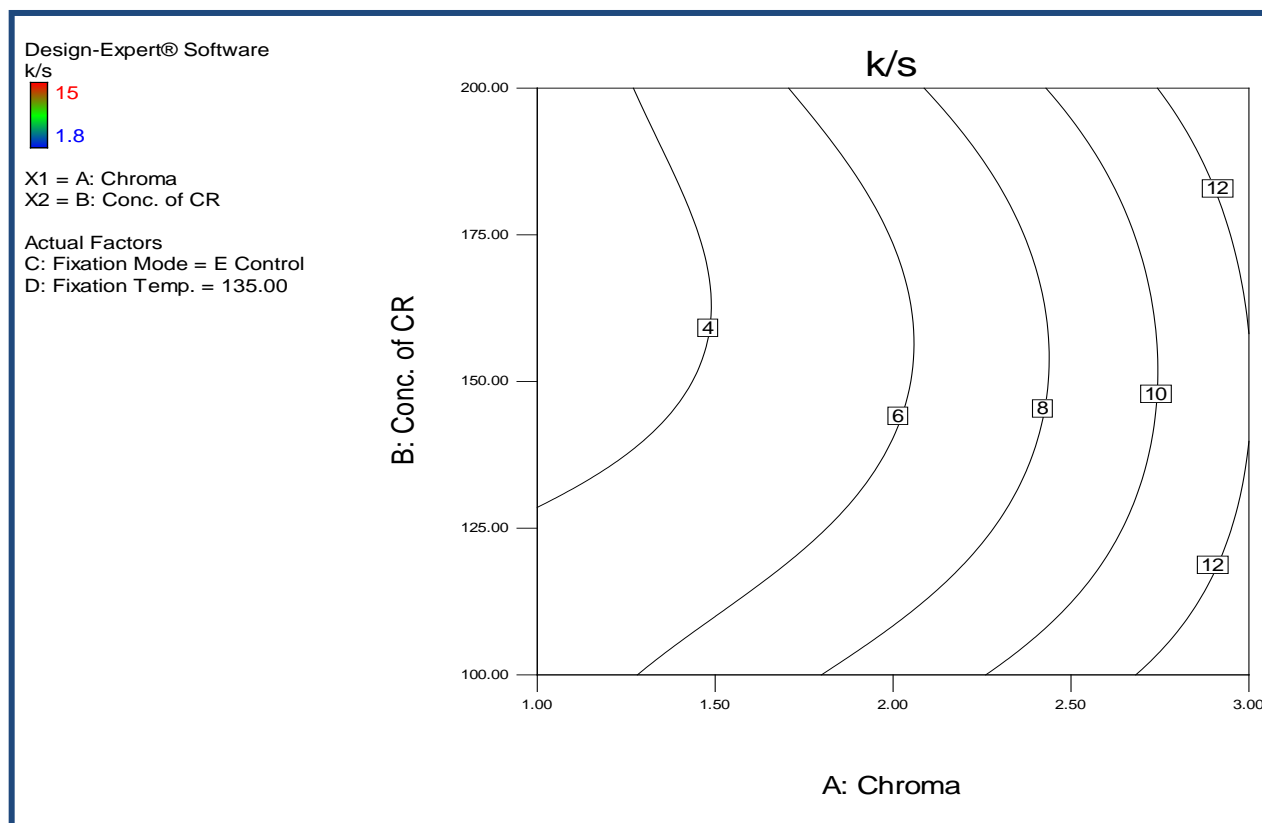**Figure 15.** Interaction plot of AB with respect to K/S

Figure 16. Contour plot representing K/S versus chroma and concentration of CR

3.3. Fitted Regression Equation of K/S

$$K/S = 4.92 + 3.40A - 0.90B + 0.38C + 0.73D + 9.042 \times 10^{-03}AB + 0.57AC + 0.12AD + 0.26BC - 0.31BD - 1.00CD + 1.44A^2$$

$$2.31B^2 + 1.18D^2 + 0.48ABC - 0.43ABD - 0.96ACD + 0.38BCD - 0.24A^2B + 0.26A^2C - 0.70A^2D - 0.14AB^2 - 0.14AD^2 \quad (2)$$

$$+0.22B^2C - 0.54B^2D + 0.080BD^2 + 0.21CD^2 - 0.049CD^2 - 1.27A^2B^2 + 0.44A^2BC + 0.053A^2CD - 0.32A^2CD -$$

$$1.20A^2D^2 + 0.43AB^2C - 0.65AB^2D - 0.69ABD^2 - 0.42ACD^2 + 0.34B^2CD - 0.91B^2D^2 - 0.029BCD^2$$

4. Conclusions

The statistical analysis of significant factors namely chroma, concentration of crease resistant and fixation temperature including ANOVA, residual analysis, model adequacy checking and regression analysis has been performed. Mathematical model has been developed based on the fitted values obtained. The range of optimum values of chroma, concentrations of crease resistant and fixation temperature that lead to maximum colour yield can be found from the developed mathematical model. The uncertainty analyses for measurements shows that the predicted values are in good agreement with experimental data and are sufficiently accurate.

ACKNOWLEDGEMENTS

REFERENCES

[1] H. Tavanai1, S. M.Taheri, M. Nasiri, "Modelling of Colour Yield in Polyethylene Terephthalate Dyeing with Statistical and Fuzzy Regression", Iranian Polymer Journal, 14 (11), 954-967 (2005)

[2] H. Tavanai, A. Z. Hamadani, M. Askari, "Modelling of Colour Yield for Selected Reactive Dyes in Dyeing Cotton Cloth by Two Phase Pad-steam Method", Iranian Polymer Journal, 15 (3), 207-217(2006)

[3] V. Vassileva, E. Valcheva, Z. Zheleva, "The Kinetic Model of Reactive Dye Fixation on Cotton Fibres", Journal of the University of Chemical Technology and Metallurgy, 43(3), 323-326 (2008)

[4] F. Asim, M. Mahmood, M. A. Siddiqui, "Optimization of process parameters for simultaneous fixation of reactive printing and crease resistant finishing using desirability function", International Conference on Systems Engineering and Engineering Management, 1098-1105 (2011*)*

[5] F. Asim, M. Mahmood, "Multi response optimization of simultaneous fixation of reactive printing and crease resistant finishing using desirability function", International Journal of Statistics and Applications, 2(6), 126-131 (2012)

[6] F. Asim, M. Mahmood, "Optimization of process parameters for simultaneous fixation of reactive printing and crease resistant finishing", Journal of Textile and apparel Technology Management, 7(3), Spring (2012)

[7] W. J. Lau, A. F. Ismail, "Application of Response Surface Methodology in pes/speek Blend NF Membrane for Dyeing Solution Treatment", Membrane Water Treatment, 1(1), 49-60 (2010)

[8] K. Ravikumar, S. Krishnan, S. Ramalingam, K. Balu, "Optimization of Process Variables by the Application of Response Surface Methodology for Dye Removal using a Novel Absorbent", Dyes and Pigments, 72(1), 66-74 (2007)

[9] T. Ramachandran, N. Gobi, V. Rajendran, C. B. Lakshmikantha, "Optimization of Process Parameters for Crease Resistant Finishing of Cotton Fabric using Citric Acid", Indian Journal of Fibre & Textile Research, 34, 359-367 (2009)

[10] A. Nazari, M. Montazer, A. Rashidi, M. Yazdashenas, M. B. Moghadam, "Optimization of Cotton Crosslinking with Polycarboxylic Acids and Nano TiO_2 using Central Composite Design", Journal of Applied and Polymer Science, 117(5), 2740-2748 (2010)

[11] K. Murugesan, A. Dhamija, I. H. Nam, Y. M. Kim, Y. S. Chang, "Decolourization of Reactive Black 5 by Laccase: Optimization by Response Surface Methodology", Dyes and Pigments, 75(1), 176-184 (2006)

[12] B. K. Körbahti, "Response Surface Optimization of Electrochemical Treatment of Textile Dye Waste Water", Journal of Hazardous Materials, 145(1-2), 277-286 (2007)

[13] F. Asim, M. Mahmood, "Reactive Printing & Crease Resistance Finishing of Cotton Fabrics. Part-I Study of Influential Factors by an Experimental Design Approach", Journal of Textile & Apparel, Technology and Management, 7(1), (2011)

[14] F. Asim, M. Mahmood, "Reactive Printing and Crease Resistance Finishing of Cotton Fabrics-Effects of Fixation Modes by $2^2.4^1$ Mixed Factorial Design", International Journal of Textile Science, 1(6), 94-100 (2012)

[15] F. Asim, M. Mahmood, "Effects of Process Parameters on Single Step Fixation of Reactive Printing and Crease Resistance Finishing of Cotton Fabrics using 2^3 Factorial Design", International Journal of Textile Science, 2(1), February (2013)

[16] S.M. Mortazavi, M.A. Alsharif, M. Jannesari, "A study on Simultaneous Fixation of Reactive Dye Printing and Crease Resist Finishing on Cotton Fabric (Effect of DMDHEU Concentration, Types of Catalyst and Drying Conditions)",