

Application of Taguchi method and ANOVA in the optimization of dyeing process on cotton knit fabric to reduce re-dyeing process

¹Wahyudin, ²Angel Kharisma, ²Richard Dimas Julian Murphiyanto, ²Muhammad Kevin Perdana, ²Tota Pirdo Kasih

¹Graduate Program, Universitas Mercu Buana, JL. Menteng Raya No. 29 Jakarta 10340, Indonesia

²Industrial Engineering Department, Faculty of Engineering, Bina Nusantara University, Jakarta, Indonesia 11480

Corresponding author: tkasih@binus.edu

Abstract. In the textile industry, tons of dyes are lost to effluents every year during the dyeing and finishing operations, due to the inefficient processes. As the dyeing process produce tons of effluents, the re-dyeing process multiplies the number. The re-dyeing process will be done when the expected color not reached that caused by the improper setting of parameters. The waste of these processes could threaten the environment. In this paper, we utilize Taguchi methods and ANOVA to obtain the optimum conditions of a dyeing process at XYZ company and to gain the percentage of contributions of each parameter. To confirm the optimum conditions obtained by using the Taguchi Method, verification test was carried out to inspect the similarity between predicted output and five experiments under the optimal conditions and the result was confirmed. The optimum conditions for a dyeing process are dye concentration 3.5%; Na₂SO₄ concentration 80g/l; Na₂CO₃ concentration 5.8 g/l; and temperature at 80 °C.

Keywords: Taguchi Method, ANOVA, S/N Ratio, Dyeing Process, Textile Industry

1. Introduction

Fashion industry has significantly evolved over the last 20 years thus speeds up the market demand [1]. In the textile industry, up to 200.000 tons of dyes are lost to effluents every year during the dyeing and finishing operations, due to the inefficiency of the dyeing process [2]. Most of the waste originated from the dyeing process could not entirely be processed in the conventional wastewater treatment due to their stability to light, temperature, water, detergents, chemicals, soap and other parameters such as bleach and perspiration persists in the environment [3]. As the dyeing process produce tons of effluents, the re-dyeing process multiplies the number, this was the problem that XYZ company faced. In terms of environmental protection, it is expected that the waste of dyeing process will be reduce by lessen the number of re-dyeing process.

One of the growing textile industry is XYZ company. Based on the data obtained from the department of quality assurance, the re-dyeing process occupies the first position of 27.3% of the total fabric defects. Dye defects require to be re-dyed until they reach the desired color. The quality of the color depends on the optimal conditions given in the process. In the dyeing process, it is generally known that many parameters including dye concentration, Na₂SO₄ concentration, Na₂CO₃ concentration and temperature will affect the achievement of desired color on cotton knit fabric.



Optimization process was done by Taguchi method with three parameters and three levels rather than full factorial DoE which examines all factors [4]. Taguchi method brings the benefit into the short running experiments due to its robust orthogonal array pattern. With the intention to lessen the number of experiment, time and cost we utilized Taguchi method. Taguchi methods have been widely utilized with the objective of obtaining information about the behavior of a given process [5]. Parameter design could determine the factors affecting quality characteristics in the manufacturing process. By selecting the proper orthogonal array (OA) based upon the parameter design, the optimum condition (optimum level of each parameter) of a process could be identified [6]. Previous researches do not use a statistical test to verify the predicted value with the result of their experiments; they only compare the values of both. In this paper we verify the values between the prediction and the experiment results with a statistical test which was t-test.

The purpose of this study was to find the optimum conditions of the dyeing process since they were unknown. The application of Taguchi method is expected to help reduce the amount of re-dyeing in the dye process.

2. Experimental Design

2.1 Material

Material used in this experiment is 100% cotton knit fabric that had undergo scouring bleaching process with Ne₁ 32^s of string number. Material preparation done by cutting the cotton knit fabric to a square shape and a weight of 5 grams. Table 1 shows the four control parameters with three levels of each parameter that were selected to examine the dyeing process of cotton knit fabrics.

Table 1. Control Parameters and Their Levels

Parameter	Code	Level			Unit
		1	2	3	
Evercion Red EXL Concentration	A	2.5	3.0	3.5	%
Na ₂ SO ₄ Concentration	B	60	70	80	g/l
Na ₂ CO ₃ Concentration	C	3.8	4.8	5.8	g/l
Temperature	D	70	80	90	°C

2.2 Identification of Control Parameters and Levels

Subsequently, nine groups combination of coded parameters has been performed and the result of the measured reflectance of the predominant wavelength at 640nm was exhibited at Table 2. The experiments were conducted by following the settings of parameters by using color spectrophotometer to measure the color strength in the dyeing process. Settings of parameters were determined by the orthogonal array L₉(3⁴). Response of this experiment is the color strength that was measured by the reflectance (R) that was adopted from Kubelka-Munk theory. This theory has been widely adopted in textile industry [7].

$$\frac{K}{S} = \frac{(1-R)^2}{2R} \dots\dots\dots (1)$$

Table 2. Measured Color Strength with Conditions Determined by Orthogonal Array

Experiment	Parameter Code				Experiment		
	A	B	C	D	R1	R2	R3
1	1	1	1	1	12.91	12.39	11.71
2	1	2	2	2	17.03	17.46	17.88
3	1	3	3	3	17.06	16.26	16.44
4	2	1	2	3	18.10	18.32	18.33
5	2	2	3	1	18.24	18.85	18.78
6	2	3	1	2	20.38	20.94	19.89
7	3	1	3	2	20.56	20.29	19.93
8	3	2	1	3	19.85	19.42	19.50
9	3	3	2	1	18.93	19.85	18.32

Taguchi used the signal-to-noise (S/N) ratio to measure the value of the quality characteristics of the choice [8]. S/N is characterized into three categories: Nominal is the better, smaller the better and larger the better [9]. In this paper, the larger the better character was applied with due to the intention to achieve higher dyeing rate on the cotton knit fabric.

Table 3. Mean (\bar{y}) and S/N Ratio

Exp No	R1	R2	R3	$\bar{y}_{\text{Exp}} = \frac{\sum_{i=1}^3 y_i}{3}$	$\text{SNR}_{\text{Exp}} = -10 \log \left(\frac{1}{3} \sum_{i=1}^3 \frac{1}{y_i^2} \right)$
1	12.91	12.39	11.71	12.34	21.80
2	17.03	17.46	17.88	17.46	24.83
3	17.06	16.26	16.44	16.59	24.39
4	18.10	18.32	18.33	18.25	25.22
5	18.24	18.85	18.78	18.62	25.40
6	20.38	20.94	19.89	20.40	26.19
7	20.56	20.29	19.93	20.26	26.13
8	19.85	19.02	19.50	19.59	25.84
9	18.93	19.85	18.32	19.03	25.58

3 Results

3.1 S/N Ratio Approach

As mentioned before, the character of S/N Ratio used in this paper is the larger the better. Therefore, the greater the delta value of a parameter is the better. The optimum conditions on this approach obtained by sorting the delta in an order of significantly affecting the process. The higher the delta value signifies the more effect its parameter contributes.

Table 4. Optimum Conditions by Utilizing S/N Ratio

	A	B	C	D
Level 1	23.67	24.38	24.61	24.26
Level 2	25.60	25.36	25.21	25.72
Level 3	25.85	25.39	25.31	25.15
Delta	2.18	1.01	0.7	1.46
Rank	1	3	4	2
Optimum	A3	B3	C3	D2

The highest plots of each parameter were chosen as could be seen in Figure 1, with the reason that the ratio set was the larger the better [10]. The same optimum conditions could be seen in Table 4 by the delta values therefore, the optimum conditions obtained by this approach are as follows: A3, D2, B3 and C3.

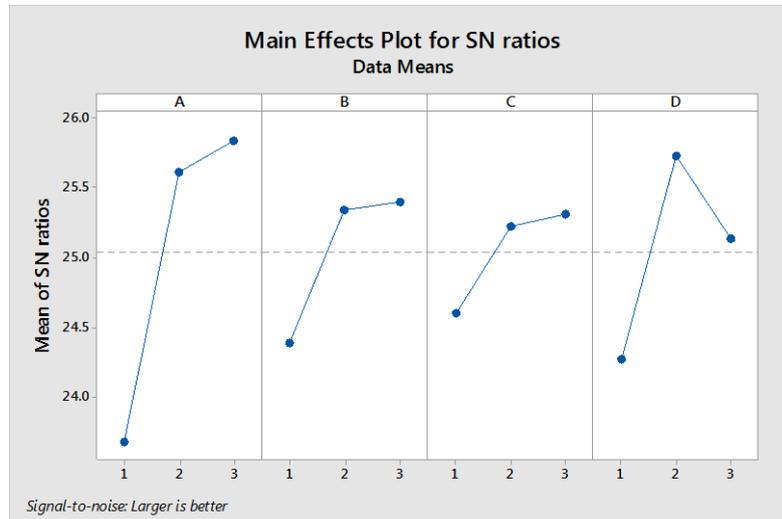


Figure 1. Main Effects Plot for S/N Ratios

3.2 ANOVA Approach

ANOVA is a statistically decision-making tool to detect differences in the average performance and helps testing the significance of all main factors. ANOVA method was utilized to understand the percentage of contribution of each parameter [11]. Table 5. shows that all parameters affect the color in the dyeing process. When F-ratio is greater than F-table then the hypothesis null is rejected and otherwise [12]. By comparing F-table ($F_{0.05,2,18} = 3.55$) to F ratios with the level of significance $\alpha = 5\%$, we found that All F ratios above are greater than 3.55 therefore, all factors are affecting the responses. Evercion red EXL concentration (A) has the biggest contribution to dyeing process followed by temperature (D), Na_2SO_4 concentration (B) and the least Na_2CO_3 concentration (C).

Table 5. ANOVA Approach

Parameter	SS	Df	MS	F-ratio	SS'	Contribution (%)
A	92.49	2	46.25	118.59	91.71	60.53
B	16.70	2	8.35	21.41	15.92	10.51
C	15.47	2	2.74	7.03	4.69	3.1
D	29.91	2	14.96	38.36	29.13	19.23
Error	6.93	18	0.39	1	10.05	6.63
SSt	151.5	26	5.83	-	151.5	100
Mean	8.806	1	-	-	-	-
SS total	8957.9	27	-	-	-	-

3.3 Verification

The purpose of the verification test was to confirm the validity of the predicted value. Minitab 17 was utilized to predict the result of a dyeing process with the optimum settings that obtained by using S/N ratio. The prediction result is 21.9856 could be seen in Figure 2.

Prediction	
S/N Ratio	Mean
27.1320	21.9856

Figure 2. Prediction by Minitab 17

We conducted five experiments under the optimum parameters to verify the predicted value that could be seen in Table 6.

Table 6. Experiments by Using Optimum Parameters

Experiment	R
1.	21.63
2.	22.15
3.	21.51
4.	21.53
5.	21.61
Mean	21.71
Standard Deviation	0.266

To compare the experiments executed under the optimal conditions with the prediction that was generated by Minitab 17 we used T-test. Hypothesis null would be verified when P value is greater than 0.05. The generated P-value is 0.064 that is greater than 0.05 so that the optimal conditions obtained by using different approaches is verified.

One-Sample T: x							
Test of $\mu = 21.9856$ vs $\neq 21.9856$							
Variable	N	Mean	StDev	SE Mean	95% CI	T	P
x	5	21.686	0.264	0.118	(21.358, 22.014)	-2.53	0.064

Figure 3. T-test by Minitab 17

4. Conclusion

By using Taguchi method and ANOVA we obtained the same result of optimum conditions. The following are the parameters (and levels) in order of significantly affecting the dye process at XYZ company: Dye Concentration (3.5%), Temperature (80°C), Na₂SO₄ Concentration (80 g/l) and Na₂CO₃ Concentration (5.8 g/l).

The greatest contribution is given by dye concentration (60.53%) followed by temperature (19.23%), Na₂SO₄ concentration (10.51%) and Na₂CO₃ Concentration (3.1%).

The predicted result compared to the experiments is verified. Therefore the obtained optimum conditions are proven to be effective.

The optimization process that performed by Taguchi method brings out the best conditions to be used in a dyeing process that could actualize a friendly environmental process in a textile industry.

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