Int. J. Electrochem. Sci., 8 **(2013)** 7991 - 8004

International Journal of
ELECTROCHEMICAL
SCIENCE
www.electrochemsci.org

Characterization of Green Corrosion Inhibitor Using Taguchi Dynamic Approach

Chernfon Tang, Jafri Mohd. Rohani[*]*, Muhammad Azizi Mat Yajid*

Department of Materials, Manufacturing & Industrial Engineering, Faculty of Mechanical Engineering, Universiti Teknologi Malaysia, 81310 UTM Skudai, Johor, Malaysia
[*]E-mail: jafri@fkm.utm.my

Received: 9 January 2013 / *Accepted:* 12 May 2013 / *Published:* 1 June 2013

The inhibitor property of *Murraya koenigii* extract and *Cymbopogen citratus* extract at in 0.25-1.0 M H_2SO_4 concentration is investigated with Taguchi dynamic approach. The results show the inhibitor property of *Murraya koenigii* extract is better than *Cymbopogen citratus* extract. The optimum parameter setting is 1.5 hours refluxing time, 6.5 %v/v *Murraya koenigii* concentration and 3.5 %v/v *Cymbopogen citratus* concentration. The robustness of the green corrosion inhibitor to change in acid concentration had been improved.

Keywords: parameter design, *Murraya koenigii*, *Cymbopogen citratus,*

1. INTRODUCTION

Recently, owing to the growing interest and attention of the world towards environmental problems and towards the hazardous effects of the use of chemicals on ecological balance, the use of plant extract as green corrosion inhibition has become the focus of study. This is very important as the plant extract is not only environmentally friendly and ecologically acceptable, but also inexpensive, readily available and renewable [1].

As far as the literature revealed, the performance of green corrosion inhibitor is governed by plant extract concentration [1-4], temperature [1-3], acid concentration [3], surface roughness [2] and additive [1,2,4]. The relationship between the corrosion rate and acid concentration follows equation 1.

$$\ln v = \ln k + bc \qquad 1)$$

Where *v* is the corrosion rate, *c* is the molar concentration of acid, *k* is the rate constant and *b* is the reaction constant [3]. In the previous study, *b* was found to be greater in presence of green corrosion inhibitor than blank acid [3,5]. This is undesirable since this indicates that the inhibition performance of green corrosion inhibitor is sensitive to change in acid concentration.

In order to study as much influencing parameters as possible for green corrosion inhibitor, the Taguchi method is introduced in this research. Compared to the conventional one-factor-at-a-time (OFAT) method used in previous study, the Taguchi method has less run while keeping a similar quality of results [6].

The Taguchi method can be applied for both static and dynamic systems. The dynamic Taguchi method is used when the target value is dependent on the input signal set by the product or process user [7].The dynamic Taguchi method had been used for optimizing electronic circuit [8], biological reduction of ethyl acetoacetate process [9] and proton exchange membrane fuel cell [10].

With dynamic Taguchi approach, this study aimed to improve the robustness of the green corrosion inhibitor performance to the change in acid concentration by studying the influenced parameter simultaneously.

2. EXPERIMENTAL

2.1. Dynamic Taguchi method

In Taguchi method, the influencing parameters is categorized into signal factor, control factor and noise factor as shown in Fig. 1.

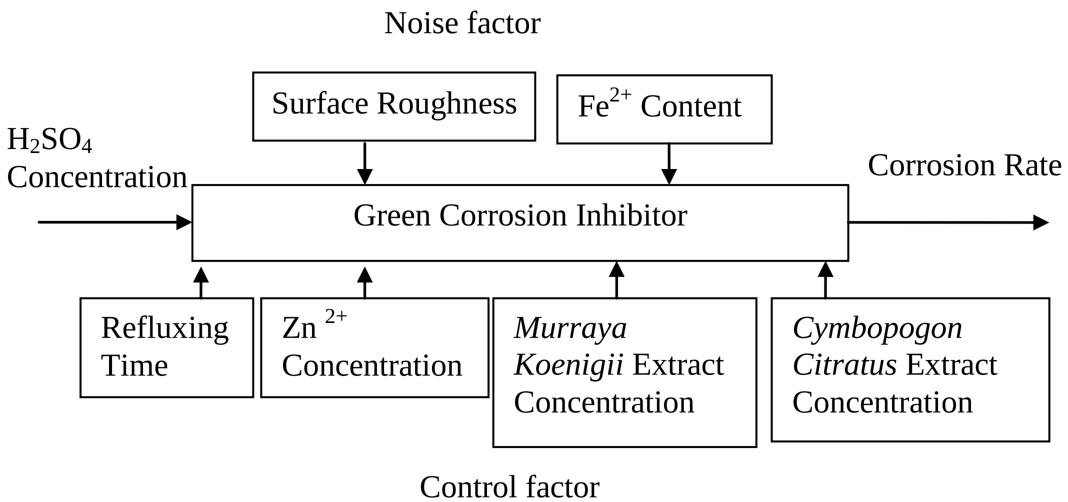

Figure 1. P-diagram

The response is defined as output of a process. The response can be classified into larger-the-better, nominal-the-better and smaller-the-better. The corrosion rate is the response in this study which has a smaller-the-better characteristic. Signal factor is variable which initials the process and sustain its function. Thus, H_2SO_4 concentration is selected as the signal factor as the H_2SO_4 involves in the corrosion reaction.

The control factor is variable that is expected to give impact on the response. The refluxing time, Zn^{2+} concentration, *Murraya koenigii* extract concentration and *Cymbopogen citratus* extract concentration are selected as control factor. The noise factor is variable that known to affect the response but it is difficult to control or uneconomical to control or unidentifiable. Fe^{2+} concentration and surface roughness are assigned as noise factor.

The level of signal factor, control factor and noise factor is shown in Table 1 and Table 2. Meanwhile, The Taguchi L_9 orthogonal array with the experimental design shown in Table 3 was used in this study.

Table 1. Level of signal factor and control factor

Factor	Level 1	Level 2	Level 3	Level 4
M: H_2SO_4 concentration (mol/dm^3)	0.25	0.5	0.75	1.0
A: Refluxing time (h)	0.5	1.5	2.5	
B: Zn^{2+} concentration (ppm)	5	25	45	
C: *Murraya koenigii* extract concentration (% v/v)	0.5	3.5	6.5	
D: *Cymbopogon citratus* extract concentration (% v/v)	0.5	3.5	6.5	

Table 2. Level of noise factor

Factor	**Fe^{2+} content (mol/dm^3)**	**Surface roughness (grits)**
N_{-1}	0.01	2000
N_{+1}	0	600

Table 3. Experimental design

Run	Control factor				Signal factor, *M*							
					1		2		3		4	
	A	B	C	D	N_{-1}	N_{+1}	N_{-1}	N_{+1}	N_{-1}	N_{+1}	N_{-1}	N_{+1}
1	1	1	1	1								
2	1	2	2	2								
3	1	3	3	3								
4	2	1	2	3								
5	2	2	3	1								
6	2	3	1	2								
7	3	1	3	2								
8	3	2	1	3								
9	3	3	2	1								

The H_2SO_4 concentration against ln(corrosion rate) relationship in equation1 can be fitted into linear regression model in equation 2 by treating former as signal factor, *M* and latter as response, *y*.

$$y = \beta_0 + M\beta_1 + \varepsilon \qquad 2)$$

Where β_0 is the interception, β_1 is the slope and ε is the error [11]. Based on the least square method, β_1 and β_0 can be estimated by equation 3 and 4.

$$\beta_1 = \frac{\sum_{j=0}^{s}\sum_{i=0}^{m}(y_{ij} - \bar{y})(M_j - \bar{M})}{m\sum_{j=0}^{s}(M_j - \bar{M})^2} \qquad 3)$$

$$\beta_0 = \bar{y} - \beta_1\bar{M} \qquad 4)$$

Where *s* is the level of signal factor, *m* is the level of noise factor, y_{ij} is the individual response, $\bar{y}$ is the average value of response, M_j is the magnitude of signal factor and $\bar{M}$ is the average value of signal factor [11].

The dynamic signal-to-noise (SN) ratio is commonly used for optimization in dynamic Taguchi approach. The dynamic SN ratio based on assumption that ideal signal to response relationship is linear. [12] However, the relationship between corrosion rate and acid concentration is non-linear in this study. As the quality loss is directly proportional to the corrosion rate, the linearized model with ln(corrosion rate) in equation 2 cannot reflect the actual quality loss. Thus, the desirability function was used to replace the dynamic SN ratio in this study.

Chang [13] suggested that the desirability, d_i for dynamic smaller-the-better is given by equation 5.

$$d_i = \exp\left(-\left(1 + \frac{1}{sm}\sum_{j=1}^{s}\sum_{i=1}^{m}\frac{y_{ijkl} - y_{ij}^{\max}}{y_{ij}^{\max}}\right)\right) \qquad 5)$$

Where y_{ijkl} is the individual observations, *s* represents the signal level and *m* represents the noise level while y_{ij}^{max} and $y_{ij}^{\min}$ are the upper specification limit and lower specification limit at the *i* th response at the *j* th signal setting respectively.

2.2. Material

The experiments were performed with carbon steel with the following composition : 0.052 wt.% C, 0.052 wt.% Mn, 0.017 wt.% Si, 0.094 wt.% Cu, 0.068 wt.% Ni, 0.033 wt.% Al, 0.01 wt.% Mo, 0.043 wt.% Cr, 0.012 wt.% S, 0.11 wt.% P and Fe balance. The carbon steel was cut into size approximately 1.7X 20 X 25 mm and drilled with 3 mm diameter drill bit. Then, the specimen was ground with successive finer grit size to 600 grits size or 2000 grits size accordingly based on Table 3. After grinding, the dimension of specimen was measure with vernier caliper. Finally, the specimen was cleaned with distilled water, ultrasonic cleaned in acetone and weighted.

2.3. Preparation of plant extract

The *Murraya koenigii* leaves and *Cymbopogen citratus* leaves were collected from the residential area. Then, the leaves was cleaned with deionized water, dried at 80 ^{o}C for 6 hours and ground into powder. The 25 g dried powder was refluxed with 250 ml distilled water for 0.5 hours, 1.5 hours and 2.5 hours respectively. The refluxed solutions were filtered and added with distilled water to make up 250 ml plant extract. The obtained extracts were kept in refrigerator. The concentration of the extracts was expressed in term of % v/v.

2.4. Gravimetric test

96 wt% H_2SO_4 and plant extracts was diluted with distilled water accordingly based on Table 3. Then, the carbon steel was immersed in the corrosive solution at room temperature for 24 hours. The corroded specimen was cleaned with towel and ultrasonic cleaned in acetone. Finally, the specimen was weighted and the corrosion rate, *CR* in $\mathrm{g/\ m^2 \cdot h}$ was given by equation 6.

$$CR = \frac{\kappa w}{A\tau} \qquad 6)$$

Where κ is a constant which is equal to 1.0 X10^4, τ is time of exposure in hours (h), to the nearest 0.01 h, *A* is the surface area in cm^2 to the nearest 0.01 cm^2 and *w* is mass loss in g, to nearest 1mg (corrected for any loss during cleaning).

The inhibitor efficiency of corrosion inhibitor can be expressed by equation 7.

$$I\ \% = \frac{CR_{\mathrm{blank}} - CR_{\mathrm{inh}}}{CR_{\mathrm{blank}}}\ X\ 100 \qquad 7)$$

Where *I* % is the inhibition efficiency while CR_{blank} and CR_{inh} represent the corrosion rate without and with inhibitor, respectively [14].

2.5. Statistical analysis

Analysis of mean (ANOM) is a statistical method for identifying the control factors which are primarily responsible for inducing variation in the mean, SN ratio and sensitivity [15]. ANOM began with determining average of the mean, SN ratio and sensitivity of each control factor at a certain level. For illusion, the mean SN of factor A, m_{Ai} in level i in a Taguchi study is given by equation 8.

$$m_{Ai} = \frac{1}{n_A}\sum_{i=1}^{L_A}(SN)_{Ai} \qquad 8)$$

Where n_A is the number of appearances of factor A in the orthogonal array and $(SN)_{Ai}$ is the SN ratio of factor A in level i [16]. After obtaining the average value for every factor at different level, the response graph was plotted.

In the Taguchi method, a control factor is considered to be significant if its influence is large compared to the experimental error as estimated by the analysis of variance (ANOVA) [17]. For an orthogonal array, assuming that there are q number of factor, k levels for a factor and for each level t, the total sum of response at t th level is represented by T_t, the total sum of responses is given by T, the total number of run is N, the number of replicates is R and the individual observations is y_{ij}, then the sum of square of the factor (SS_{factor}), total sum of square, (SS_T), sum of square error (SS_E) degree of freedom (DOF), mean square (MS_{factor}) and F_o ratio for factor (F_{factor}) are given by equation 10-14 respectively [16].

$$SS_{factor} = \frac{k}{N \times R}\sum_{t=1}^{k} T_t^2 - \frac{T^2}{N \times R} \qquad 9)$$

$$SS_T = \sum_{i=1}^{N}\sum_{j=1}^{n} y_{ij}^2 - \frac{T^2}{N \times R} \qquad 10)$$

$$SS_E = SS_T - \sum_{factor=1}^{q} SS_{factor} \qquad 11)$$

$$DOF = k - 1 \qquad 12)$$

$$MS_{factor} = \frac{SS_{factor}}{DOF} \qquad 13)$$

$$F_{factor} = \frac{MS_{factor}}{SS_T} \qquad 14)$$

Other than verifying the result with F_o ratio, the ANOVA table also can be used to evaluate the percentage contribution for a factor, ρ_{factor} using equation 15 [18].

$$\rho_{factor} = \frac{SS_{factor}}{SS_T} \qquad 15)$$

After determining the significant factor in the experiment, a predicted model was constructed based on the ANOM result. Then, a confirmation run was conducted and its result should fall within the confidence interval (CI) which can be calculated using the Student's *t*-distribution as listed in equation 16.

$$\mathrm{CI} = t_\alpha(f_e) \times \sqrt{\mathrm{MS}_e \times \left(\frac{1}{m_e} + \frac{1}{r}\right)} \qquad 16)$$

Where α is the significance level, f_e is the degrees of freedom of the pooled error, MS_e is the mean square of the pooled error, r is the sample size for the confirmation run and the effective sample size, m_e, which is given by equation 17 [10].

$$m_e = \frac{N}{1 + DOF_{opt}} \qquad 17)$$

Where N is the number of experiments in the Taguchi study and DOF_{opt} is the total degree of freedom associated with items used in estimating the SN ratio or β_1 [10].

3. RESULTS AND DISCUSSION

3.1. Corrosion rate

After gravimetric test, the corrosion rate was computed based on the weight loss of steel by equation 6 as shown in Table 4. From the result, response graph for mean was constructed as shown in Fig. 2. Then, ANOVA was conducted to obtain the significant factor influencing the corrosion rate as shown in Table 5.

From the ANOVA result, the factor C and D which is the *Murraya koenigii* extract concentration and *Cymbopogen citratus* extract concentration was found to have significant influence on the corrosion rate as their *P*-value in Table 5 is smaller than 0.05.

The inhibitor property of *Murraya koenigii* extract is better than *Cymbopogen citratus* extract as the percentage contribution for *Murraya koenigii* extract concentration is 0.38 compared to 0.11 of *Cymbopogen citratus* extract concentration.

Table 4. Gravimetric test result

Trial	Corrosion rate, g/m^2.h									Desirability
	M = 0.25		*M* = 0.5		*M* = 0.75		*M* = 1.0		Mean	
	N_{-1}	N_{+1}	N_{-1}	N_{+1}	N_{-1}	N_{+1}	N_{-1}	N_{+1}		
1	0.88	1.05	1.07	1.62	1.34	1.76	2.00	2.15	1.48	0.57
2	0.51	0.57	0.57	0.76	0.70	0.84	0.81	0.94	0.71	0.76
3	0.42	0.48	0.48	0.62	0.59	0.73	0.67	0.87	0.61	0.79
4	0.42	0.55	0.46	0.64	0.55	0.67	0.71	0.79	0.60	0.79
5	0.50	0.63	0.70	0.81	0.82	0.91	0.96	1.04	0.80	0.74
6	0.87	0.96	0.93	1.08	1.10	1.24	1.24	1.34	1.10	0.65
7	0.44	0.56	0.53	0.62	0.62	0.80	0.76	0.88	0.65	0.78
8	0.84	0.98	1.09	1.20	1.32	1.51	1.42	1.68	1.15	0.62
9	0.57	0.64	0.79	0.91	1.13	1.01	1.27	1.38	0.96	0.69
Baseline	2.24	2.29	2.40	2.59	2.42	2.68	2.87	2.84	2.57	
	1.76	2.05	2.09	2.26	2.83	2.99	3.36	3.45		

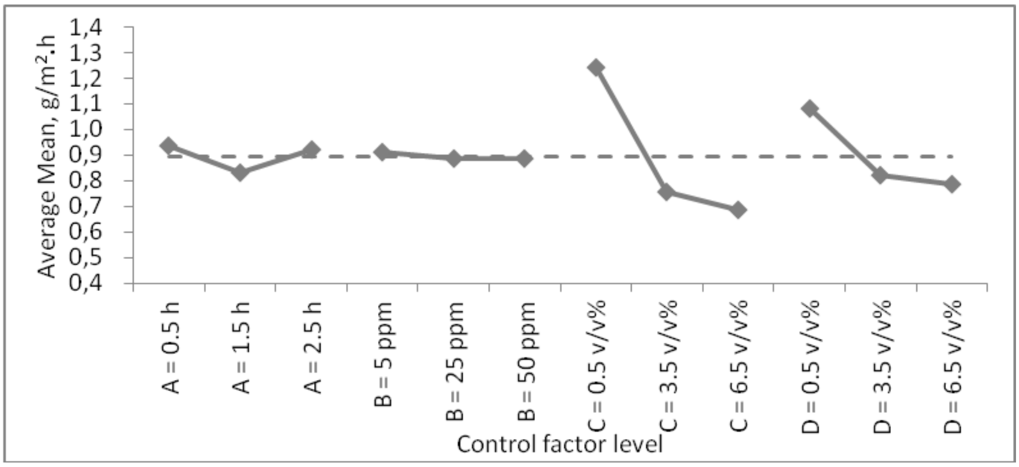

Figure 2. Response graph for mean

Table 5. ANOVA result for mean

Factor	Average mean by factor level, g/m^2.h			Sum of Square	Degree of Freedom	Mean Square	F_0	*P*-value	percentage contribution
	1	2	3						
A	0.93	0.83	0.92	0.155	2	0.077	0.87	0.425	0.01
B	0.91	0.89	0.89	0.009	2	0.005	0.05	0.950	0.00
C	1.24	0.76	0.68	4.419	2	2.209	24.74	0.000	0.38
D	1.08	0.82	0.79	1.258	2	0.629	7.04	0.002	0.11
error				5.716	64	0.089			0.50
total				11.557	72				

For computing desirability in table 4, the average corrosion rate in blank solution (baseline) was assumed as the y_{ij}^{max} in equation 5. This assumption was made because the corrosion rate in the inhibited solution cannot exceed the corrosion rate in blank solution, otherwise, the use of green corrosion inhibitor is undesirable as it make the situation worse. Based on the response graph in Fig. 3, an assumption that factor B is insignificant was made, thus factor B was assigned as pooled error in ANOVA shown in table 6. The ANOVA result showed that *Murraya koenigii* extract concentration and *Cymbopogen citratus* extract concentration have significant influence on the desirability.

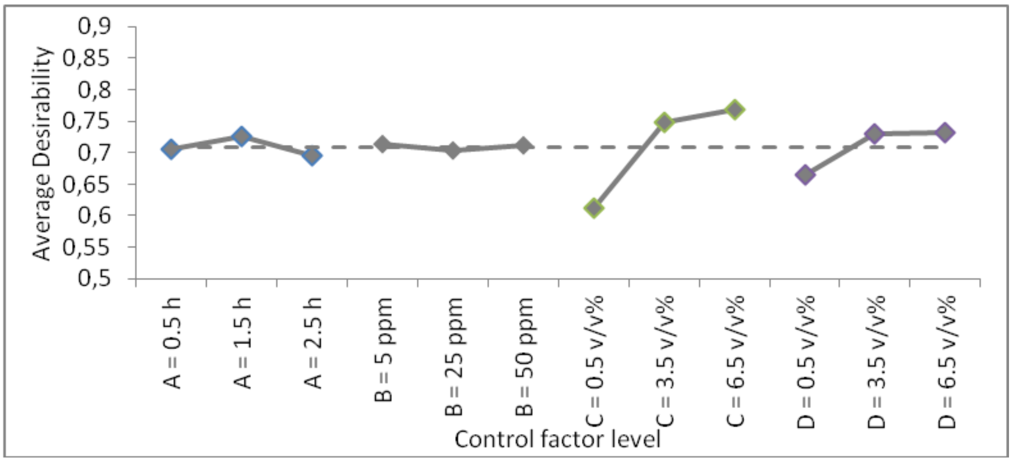

Figure 3. Response graph for desirability

Table 6. ANOVA result for desirability

Factor	Desirability by factor level			Sum of Square	Degree of Freedom	Mean Square	F_0	*P*-value	percentage contribution
	1	2	3						
A	0.71	0.73	0.70	0.0015	2	0.0008	Pooled		0.03
B	0.71	0.70	0.71	0.0002	2	0.0001	Pooled		0.00
C	0.61	0.75	0.77	0.0433	2	0.0217	50.74	0.0014	0.80
D	0.67	0.73	0.73	0.0088	2	0.0044	10.30	0.0264	0.16
error				0.0000	0				
total				0.0538	8				
pooled error				0.0017	4	0.0004			

3.2. Regression model

By taking natural logarithm on the corrosion rate, β_0 and β_1 was obtained based on equation 3-6 as shown in Table 7.

Table 7. β_0, β_1 and SN ratio for experiment 2

Trial	ln(corrosion rate), g/m^2.h								β_0	β_1
	M = 0.25		*M* = 0.5		*M* = 0.75		*M* = 1.0			
	N_{-1}	N_{+1}	N_{-1}	N_{+1}	N_{-1}	N_{+1}	N_{-1}	N_{+1}		
1	-0.13	0.05	0.07	0.48	0.30	0.57	0.69	0.77	-0.26	0.98
2	-0.67	-0.56	-0.57	-0.27	-0.36	-0.17	-0.22	-0.06	-0.76	0.64
3	-0.86	-0.73	-0.73	-0.47	-0.53	-0.31	-0.40	-0.14	-0.96	0.70
4	-0.86	-0.59	-0.79	-0.45	-0.60	-0.40	-0.34	-0.23	-0.89	0.57
5	-0.69	-0.45	-0.36	-0.21	-0.20	-0.10	-0.04	0.04	-0.71	0.74
6	-0.14	-0.05	-0.07	0.08	0.10	0.21	0.22	0.29	-0.22	0.48
7	-0.82	-0.58	-0.64	-0.49	-0.47	-0.23	-0.28	-0.13	-0.88	0.68
8	-0.17	-0.02	0.09	0.18	0.27	0.41	0.35	0.52	-0.25	0.72
9	-0.56	-0.45	-0.23	-0.10	0.12	0.01	0.24	0.32	-0.73	1.04
Baseline	0.81	0.83	0.88	0.95	0.88	0.98	1.05	1.04	0.58	0.55
	0.56	0.72	0.74	0.82	1.04	1.10	1.21	1.24		

The response graph for β_0 and β_1 was constructed as shown in Fig. 4 and 5. As the sum of square error is equal to zero in the ANOVA table for β_0 and β_1 as shown in Table 8 and 9, pooled error was used for ANOVA. The pooled error is obtained by assuming the insignificant parameter in the response graph has no effect on the β_0 or β_1, so their variation is due to the error in the experiment.

Factor A was treated as pooled error for β_0 based on Fig. 4 and thereby the ANOVA result showed that only factor C, which is the *Murraya koenigii* extract concentration is affecting the β_0 significantly while the rest is the pooled error in the experiment.

Factor B was treated as pooled error for β_1 based on Fig. 5 and thereby the ANOVA result showed that factor A and D, which is the refluxing time and *Cymbopogen citratus* extract concentration have significant effect on the β_1 while the rest is the pooled error in the experiment.

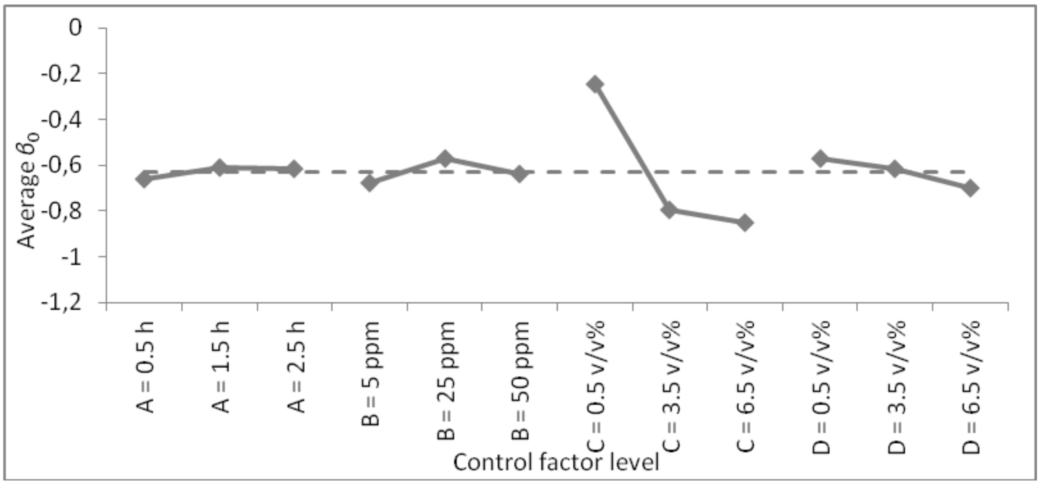

Figure 4. Response graph for β_0

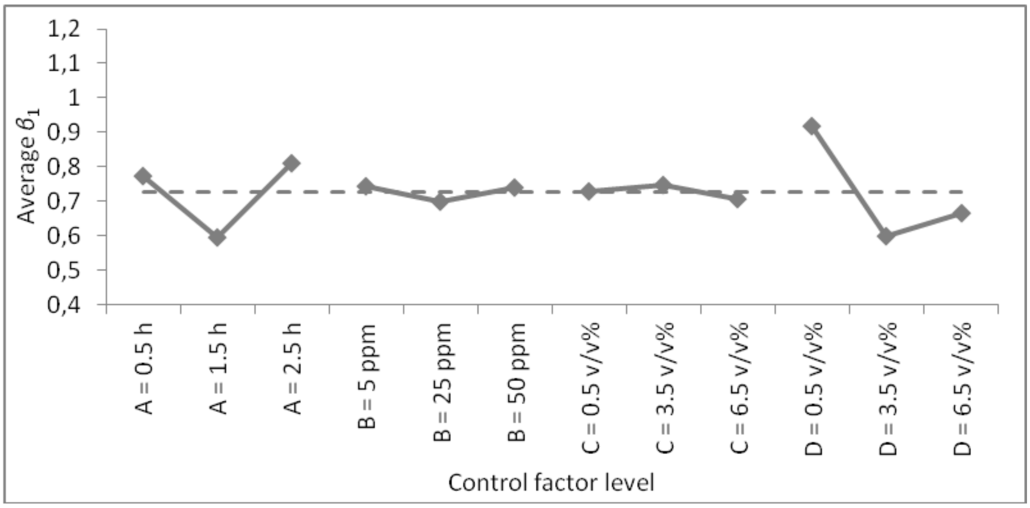

Figure 5. Response graph for β_1

Table 8. ANOVA result for β_0

Factor	Average β_0 by factor level			Sum of Square	Degree of Freedom	Mean Square	F_0	*P*-value	percentage contribution
	1	2	3						
A	-0.66	-0.61	-0.62	0.005	2	0.002	Pooled		0.01
B	-0.68	-0.57	-0.64	0.017	2	0.008	Pooled		0.02
C	-0.24	-0.79	-0.85	0.670	2	0.335	41.9	0.00	0.93
D	-0.57	-0.62	-0.70	0.027	2	0.013	Pooled		0.04
error				0.000	0				
total				0.718	8				
pooled error				0.048	6	0.008			

Table 9. ANOVA result for β_1

Factor	Average β_1 by factor level			Sum of Square	Degree of Freedom	Mean Square	F_0	*P*-value	percentage contribution
	1	2	3						
A	0.77	0.60	0.81	0.078	2	0.0392	24.49	0.01	0.31
B	0.74	0.70	0.74	0.004	2	0.0018	Pooled		0.01
C	0.73	0.75	0.71	0.003	2	0.0014	Pooled		0.01
D	0.92	0.60	0.67	0.172	2	0.0858	53.59	0.00	0.67
error				0.000	0				
total				0.256	8				
pooled error				0.006	4	0.0016			

2.3. Confirmation run

Based on the ANOM result, the predicted desirability ($\hat{d}$), predicted β_0 ($\widetilde{\beta_0}$) and predicted β_1 ($\widetilde{\beta_1}$) are estimated as shown by equation 18-20.

$$\hat{d} = \bar{d} + (\bar{d}_{C_n} - \bar{d}) + (\bar{d}_{D_n} - \bar{d}) \quad 18)$$

$$\widetilde{\beta_0} = \bar{\beta}_0 + (\bar{\beta}_{0,C_n} - \bar{\beta}_1) \quad 19)$$

$$\widetilde{\beta_1} = \bar{\beta}_1 + (\bar{\beta}_{1,A_n} - \bar{\beta}_1) + (\bar{\beta}_{1,D_n} - \bar{\beta}_1) \quad 20)$$

Where $\bar{d}$ is the average d_i, $\bar{d}_{C_n}$ is the average d_i of factor C at level n, $\bar{d}_{D_n}$ is the average d_i of factor D at level n, $\bar{\beta}_0$ is the average β_0, $\bar{\beta}_{0,C_n}$ is the average $\bar{\beta}_0$ of factor C at level n, $\bar{\beta}_1$ is the average β_1, $\bar{\beta}_{1,A_n}$ is the average $\bar{\beta}_1$ of factor A at level n and $\bar{\beta}_{1,D_n}$ is the average $\bar{\beta}_1$ of factor D at level n.

.

Table 10. Corrosion rate and desirability of confirmation run

Trial	Corrosion rate, $g/m^2.h$									Desirability
	M = 0.25		M = 0.5		M = 0.75		M =1.0		Mean	
	N_{-1}	N_{+1}	N_{-1}	N_{+1}	N_{-1}	N_{+1}	N_{-1}	N_{+1}		
10	0.46	0.61	0.51	0.71	0.63	0.89	0.71	1.00	0.65	0.77
11	0.42	0.56	0.45	0.75	0.49	0.80	0.59	0.87		
Predicted value										0.79 ± 0.09

Table 11. β_1 and β_0 of confirmation run

Trial	ln(corrosion rate)								β_0	β_1
	M = 0.25		M = 0.5		M = 0.75		M = 1.0			
	N_{-1}	N_{+1}	N_{-1}	N_{+1}	N_{-1}	N_{+1}	N_{-1}	N_{+1}		
10	-0.79	-0.50	-0.68	-0.35	-0.46	-0.12	-0.34	0.00	-0.82	0.57
11	-0.86	-0.57	-0.79	-0.29	-0.72	-0.23	-0.53	-0.14		
Predicted value									0.85 ± 0.11	0.47 ± 0.11

Optimization began with optimizing factor influencing the desirability to achieve higher desirability. Factor C at level 3 gives the highest desirability based on Fig. 3. Meanwhile, factor D has almost similar high value desirability at level 2 and 3. Next, the β_1 was considered for optimization. The factor A gives the smallest β_1 at level 2 and factor B gives the smallest β_1 at level 2 according to figure 5. As the factor C has not significant effect on desirability, β_1 and β_0, its level was picked arbitrarily. Thus, the optimum parameter setting is $A_2B_1C_3D_2$.

The confirmation run result at $A_2B_1C_3D_2$ was summarized in Table 10 and Table 11. The obtained values of desirability, β_1 and β_0 are within the confidence interval. So, the predicted models in equation 18-20 are adequate for predicting desirability, β_1 and β_0

3.4. Discussion

The average of inhibitor efficiency at N_{-1} and N_{+1} for optimum parameter setting is used for benchmarking with the previous studies as shown in Table 12. The obtained inhibitor efficiency in this study is slightly lower compared to the previous studies as shown in Table 12. However, the obtained inhibitor efficiency has virtually no change when the H_2SO_4 concentration increase from 0.5 M to 1.0 M because the different in reaction constant, *b* (which is equal to β_1) in the inhibited solution and blank solution is not significant in the confirmation run compared to the previous literature. In other words, the performance of green corrosion inhibitor is more robust at the optimum parameter setting.

Table 12. Benchmarking with previous study

Green corrosion inhibitor	Inhibitor efficiency, %		Blank / inhibited solution	b, M^{-1}	k, $g/m^2.h$	Reference
	M = 0.5	M = 1.0				
Murraya koenigii (6.5 v/v%) and *Cymbopogen citratus* (3.5 v/v %)	74.3	74.7	Blank	0.55	1.79	Obtained result in the confirmation run
			Inhibited	0.57	0.44	
Bamboo leaves (200 ppm)	86*	81*	Blank	0.51	6.28	[3]
			Inhibited	0.89	6.82	
Ginkgo leaves (100 mg L^{-1})	82*	77*	Blank	0.63	10.23	[5]
			Inhibited	1.24	1.27	

* Estimated value based on the figure or data provided in the previous studies

The obtained *b* for blank solution and inhibited solution at optimum setting is agree well with the previous studies [3,5] as the *b* is bigger in inhibited solution than blank solution. The rate constant, *k* (which is equal to e^{β_0}) is also aligned well with the previous study [3,5] as the *k* is bigger in blank solution than inhibited solution.

The effect of Zn^{2+} concentration has insignificant effect on the corrosion rate in this study. This result is supported by previous research as the high hydrogen ion concentration will shift equilibrium of formation of protective $Zn(OH)_2$ layer to the left, thus Zn^{2+} is less effective in acid medium [4].

A previous study on *Murraya koenigii* leaves extract obtained higher inhibitor efficiency which is 94.66% for mild steel immersing in 0.5 M H_2SO_4 at 308 K for 3 h [19]. The higher inhibitor efficiency in the previous study is believed to be caused by a shorter immersion time of 3 h in the previous study compared to 24 h in this study because the inhibitor efficiency of *Murraya koenigii* leaves extract decreases with immersion time in H_2SO_4 [19].

4. CONCLUSIONS

The green corrosion inhibitor made up by *Murraya koenigii* extract and *Cymbopogon citratus* extract has successfully reduced the corrosion rate of carbon steel in H_2SO_4 medium. The inhibitor property of *Murraya koenigii* extract is better than *Cymbopogon citratus* extract.

The sensitivity, β_1 of green corrosion inhibitor to change with H_2SO_4 concentration can be reduced by adjusting the refluxing time and concentration of *Cymbopogon citratus* extract. Meanwhile, the β_0 is governed by the concentration of *Murraya koenigii* extract.

The confirmation run has validated the predicted model in equation 18-20 as the obtained result is within the confident interval. The sensitivity of green corrosion inhibitor to change in green corrosion inhibitor concentration had been reduced in this study.

References

1. E.E. Oguzie, *Port. Electrochim. Acta*, 26 (2008) 30
2. E.A. Noor, *Mater. Chem. Phys.*, 131 (2011) 160
3. X. Li, S. Deng and H. Fu *Corros. Sci.*, 62 (2012) 163
4. M. Sangeetha, S. Rajendran, J. Sathiyabama, A. Krishnaveni, P. Shanthy, N. Manimaran and B. Shyamaladevi *Port. Electrochim. Acta*, 29 (2011) 429
5. S. Deng and X. Li *Corros. Sci.*, 55 (2012) 407
6. S.M. Tasirin, S.K. Kamarudin, J.A. Ghani and K.F. Lee *J. Food Eng.*, 80 (2007) 695
7. K.L. Tsui *IEE Trans.*, 31 (1999) 113
8. G. Taguchi *IEE Trans. Reliab.*, 44 (1995) 225
9. K.L. Hsieh, L.I. Tong, H.P. Chiu and H.Y. Yeh *Comput. Ind. Eng.*, 49 (2005) 556
10. W.L. Yu, S.J. Wu and S.W. Shiah *Int. J. Hydrogen Energy*, 35 (2010) 11138
11. A. Miller and C.F.J. Wu *Stat. Sci.*, 11 (1996) 122
12. A. Miller and C.F.J. Wu *Qual. Reliab. Eng. Int.*, 12 (1996) 75
13. H.H. Chang *Expert Syst. Appl.*, 35 (2008) 1095
14. M.A. Abu-Dalo, A.A. Othman and N.A.F. Al-Rawashdeh *Int. J. Electrochem. Sci.*, 7 (2012) 9303
15. H.H. Tsai, D.H. Wu, T.L. Chiang and H.H. Chen *Sensor*, 9 (2009) 1394
16. K. Yang and B. El-Haik *Design for Six Sigma: A Roadmap for Product Development*, McGraw-Hill (2003)
17. D.H. Wu and M.S. Chang *Mater. Sc. Eng. A*, 379 (2004) 366
18. N. Raghunath and P.M. Pandey *Int. J. Mach. Tools Manuf.*, 47 2007 985
19. N.A., Quraishi, A., Singh, V.K., Singh, D.K., Yadav and A.K., Singh. *Mater. Chem. Phys.*, 122 (2010) 114