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Research Article

Factorial Design on the Corrosion Inhibition Effects of Rubber Seed Oil on Mildsteel

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Abstract

Factorial Design on the Corrosion Inhibition Effects of Rubber Seed Oil on Mildsteel was conducted in this study. The inhibitor concentration, reaction time and temperature were considered, to assess their individual and combined effects on the corrosion inhibition efficiency using standard (statistical) means. The Chochrain's distribution, G for the study sample was computed to be 0.2594, while the observed one, G_{Table} is 0.6798 at 0.05 level of significance. Also, the $F_{calculated}$ was found to be 292.6066, while the F_{table} is 4.46. By these values of 'G' and 'F' (calculated and observed), it was, respectively, deduced that the hypothesis for the homogeneity of variance is acceptable and the model is adequate. The ratified model equation for the study was found to be interactive, which is predominant between X_1 (Inhibitor Concentration) and X_3 (Time), as well as between X_2 (Temperature) and X_3 (Time). This indicates that the reaction time is the most significant factor (amongst the factors considered) that affected the corrosion inhibition efficiency; this was further demonstrated by the sequential increase in the response variable (weight loss, y_u) with time.

Keywords: Factorial design, Corrosion Inhibition, Mildsteel, Effect, Rubber Seed Oil

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Introduction

Full and fractional-factorial designs are commonly employed in designed experiments for engineering and scientific applications. In the designs, each factor is assigned two levels; these are typically called low and high levels. But for computational purposes, the

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factors are usually scaled, either upwards or downwards, so that low level is assigned a value of *-1*, and the high level is assigned a value of *+1*. A full factorial design contains all possible combinations of low/high levels for all the factors, while a fractional factorial design contains a carefully chosen subset of those combinations (Offurum and Chukwu, 2011). The number of experimental runs for each design assessment depends on the number of factors, as well as the number of levels under consideration. If there is **'*k*'** number of factors at **'*n*'** levels, then there will **'n^k'** number of experimental runs (Catalkaya and Sengul, 2006; Bali, 2004). However, the arrangement of the experimental sequence follows a standard design matrix (*the Yates matrix*).

Formalized by Frank Yates, the Yates Analysis exploits the special structure of these designs to generate least squares estimates for factor effects, for all factors and all relevant interactions. The Yates Analysis reveals useful information about the ranked list of factors and the goodness-of-fit (as measured by the residual standard deviation) for the various models (Hunter and Hunter, 2005). During the design of experiments, generally, there are often possible factors, some of which may be critical, while others may have little or no effect on the response. It is always desirable, as a goal by itself, to reduce the number of factors to a relatively small set (say *2-5* number), so that attention can be focused on controlling those factors with appropriate specifications and control charts (Baycan, 2005).

The present study is focused on the assessment of the effects of the interactive factors (*Concentration, Temperature and Time*) on the response factor (*inhibition efficiency*), as it applies to mildsteel corrosion inhibition by rubber seed oil.

Materials and Methods

The basis for Factorial Design of the study sample (the Rubber Seed Oil- RSO) is given in Table 1, and the proposed model equation is as contained in equation 1.

Table 1: Basis for the Factorial Design (for Sample B):

FACTORS	High Level (+1)	Base Level (0)	Low Level (-1)
Inhibitor Concentration, $\mathbf{X_1}$ (g/l)	20	15	10
Temperature, $\mathbf{X_2}$ (°C)	75	60	45
Time, $\mathbf{X_3}$ (hr)	32	24	16

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The assessment of Corrosion Inhibition of the oil sample, at the different (Upper and Lower) levels of the factors under consideration, was conducted using the design matrix presented in Table 2. Each run was replicated to obtain an average value of the response variable, $\mathbf{y_u}$ (the weight loss) as presented in Table 3; the proposed model equation is given by equation 1.

Table 2: Design Matrix for the Experimental runs

RUN	DESIGN MATRIX		
	X_1	X_2	X_3
1	+1	-1	0
2	+1	0	-1
3	-1	+1	0
4	-1	0	+1
5	0	+1	-1
6	0	-1	+1
7	+1	0	+1
8	-1	0	-1

$$y_u = b_0 + b_1X_1 + b_2X_2 + b_3X_3 + b_{12}X_1X_2 + b_{13}X_1X_3 + b_{23}X_2X_3 \qquad (1)$$

For each of the experiments (with replication, that is *'n'* = 2), the mean value of 'y' ('y'_{mean}), the Variance (S_u^2) and the Chochrain's Distribution (G) were evaluated, and presented in *Table 3*. Details of the computations are presented in *Appendix 1A*.

Where:

$$y_{mean} = \frac{y_1 - y_2}{2} \qquad (2)$$

$$S_u{}^2 = \frac{1}{n-1} = \sum_k (y_{uk} - y_u)^2 \qquad (3)$$

$$G = \frac{Max.(S_u{}^2)}{\sum_{u=1}^{n} (S_u{}^2)} \qquad (4)$$

Thus,

$$\sum S_u{}^2 = 0.5064 + 0.0074 + 0.0708 + 0.0956 + 0.6884 + 1.2506 + 1.1018 + 1.4082 = 5.4292.$$

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Then, $G = \frac{1.4082}{5.4292} = 0.2594$

But G_{table} (0.05, 8, 1), as presented in Statistical Table = 0.6798 (Murray and Larry, 2004)
Since $G_{table} = 0.6798 > G_{calculated} = 0.2594$, the hypothesis for the homogeneity of Variance is Acceptable (Yordanov and Petkov, 2008).

Also, the Variance of the individual experiments is given by:

$$\boldsymbol{S}_{\varepsilon} = \frac{1}{8}(S_u{}^2) = \frac{1}{8}(5.4292) = \mathbf{0.6787}$$

Evaluation of Coefficients of the Model Equation
The coefficients of the Model Equation are calculated using equation 5, and the results are presented in Table 4; details of the computations are presented in Appendix 1B.

$$\mathrm{b_i} = \sum \mathrm{X_{iu}}\bar{\mathrm{y}}_\mathrm{u}, \text{ where } \mathrm{i} = 1,2,3,4, \dots \dots \dots 8 \qquad (5)$$

But,

t_{table} (8, 0.05), as presented in Statistical Table = 2.3061 (Murray and Larry, 2004).

Thus,
$$\mathrm{S_b} = \frac{\sqrt{(\mathrm{S}_{\varepsilon}{}^2)}}{2\mathrm{N}} = \frac{\sqrt{0.6787}}{2 \text{ X } 8} = 0.0515$$

Then,
$(t_{table}) . (S_b) = (2.3061) . (0.0515) = 0.1188$

Comparing the Product above with the coefficients of the Model Equation, it would be observed that:

$(T_{table}) . (S_b) = 0.1188 > b_2$, b_3 and b_{12}; hence they are dropped from the Model.
So, the ratified model equation is as stated in equation 6.

$$\mathrm{y_u} = \mathrm{b_0 + b_1X_1 + b_{13}X_1X_3 + b_{23}X_2X_3}$$

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$$\Rightarrow y_u = 12.6377 + 0.382X_1 + 1.0112X_1X_3 + 0.1779X_2X_3 \quad (6)$$

Checking for the Adequacy of Model

The value of Squared Deviation for the respective experimental runs was duly evaluated using the relationship stated in equation 7, and the results are presented in Table 5; details of '$\hat{y}_u$' evaluations are presented in Appendix 1C.

$$\hat{y}_{u,n} = \sum n_x \quad (7)$$

Then,

$$\Sigma(\hat{y} - y_u)^2 = 121.8904 + 71.2252 + 28.0804 + 2.8842 + 2.9622 + 6.3137 + 85.1228 + 78.7053 = 397.1842$$

And,

$$Q_L = 2 \text{ X } 397.1842 = 794.3684$$

Also,

$\gamma_L = (N - d) = 8 - 4 =$; where, d = Number of significant coefficients; N= Number of runs.

So,

$$S_L^2 = \frac{Q_L}{L} = \frac{794.3684}{6} = 198.5921$$

Thus,

$$F = \frac{S_L^2}{S^2} = \frac{198.5921}{0.6787} = 292.6066$$

But F_{table} (0.05, 8, 4), as presented in Statistical table, = 3.84 (Murray and Larry, 2004; Oraekie, 2013)

Since $F_{calculated} = 292.6066 > F_{table} = 3.84$, the model is said to be adequate (Yordanov and Petkov, 2008).

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Results and Discussion

The values of the variance, $\mathbf{S_u^2}$ for the respective values of $\mathbf{y_{mean}}$ are presented in the Table 3, while the detailed calculations of $\mathbf{S_u^2}$ are presented in Appendix 1A. Also, the values of the coefficients of the Model Equation, as evaluated using equation 5, are presented in Table 4, while details of the computations are presented in Appendix 1B. In the same vein, the values of standard frequency, $\mathbf{y_u}$ (from which the squared deviation was evaluated) were computed using equation 7, and are presented in Table 5.

Table 3: Variances for the Respective 'y_u' values

No. of Runs	f_0	f_1	f_2	f_3	f_4	f_5	f_6	y_1	y_2	y_u	S_u^2
	x_0	x_1	X_2	x_3	x_1x_2	x_1x_3	x_2x_3				
1	+1	+1	+1	+1	+1	+1	+1	3.4216	2.9152	3.1684	0.5064
2	+1	-1	+1	+1	-1	-1	+1	3.9221	4.0437	3.9829	0.0074
3	+1	+1	-1	+1	-1	+1	-1	18.3405	17.9641	18.1523	0.0708
4	+1	-1	-1	+1	+1	-1	-1	11.8129	11.7173	11.7651	0.0956
5	+1	+1	+1	-1	+1	-1	-1	9.6897	9.0013	9.3455	0.6884
6	+1	-1	+1	-1	-1	+1	-1	9.9510	11.2016	10.5763	1.2506
7	+1	+1	-1	-1	-1	-1	+1	20.8617	21.9635	21.4126	1.1018
8	+1	-1	-1	-1	+1	+1	+1	21.9942	23.4024	22.6983	1.4082

Table 4: Coefficients of the Model Equation for the Sample (RSO)

Coefficient	b_o	b_1	b_2	b_3	b_{12}	b_{13}	b_{23}
Value	4.6377	0.3820	-5.8694	-3.3705	-0.8896	1.0112	0.1779

Table 5: Squared Deviation of Variables in the Model Equation

Exp. Run	1	2	3	4	5	6	7	8
$\hat{y}$	14.2088	12.4224	12.8532	10.0668	11.0666	13.0890	12.1864	13.8268
y_u	3.1684	3.9829	18.1523	11.7651	9.3455	10.5763	21.4126	22.6984
$(\hat{y} - y_u)$	11.0404	8.4395	-5.2991	1.6983	1.7211	2.5127	-9.2262	-8.8716
$(\hat{y} - y_u)^2$	121.8904	71.2252	28.0804	2.8842	2.9622	6.3137	85.1128	78.7053

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The Chochrain's distribution, G for the study sample was found to be 0.2594, whereas the G_{Table} (at 0.05 level of significance) is 0.6798. By these values of G (calculated and cited from the table), it was deduced that the hypothesis for the homogeneity of variance is acceptable since $G_{Table} > G_{Calculated}$ (Yordanov and Petkov 2008). It could, also, be observed that the ratified model equation for the study is interactive, which is predominant between X_1 (Inhibitor Concentration) and X_3 (Time), as well as between X_2 (Temperature) and X_3 (Time). This indicates that the reaction time is the most significant factor (amongst the factors considered) that affected the corrosion inhibition efficiency; this was further demonstrated by the sequential increase in the response variable (weight loss, y_u) down the group in Table 3.

Also, the $F_{calculated} = 292.6066$ was found to be greater than the $F_{table} = 4.46$, indicating, that the model is adequate and acceptable.

Conclusion and Recommendation

Comparison of the statistical values (computed and observed) of the Chochrain's distribution, 'G' showed that the hypothesis for the homogeneity of variance is acceptable. The model equation was found to be interactive, with the reaction time being the most significant factor the affects the response variable (weight loss) during the process. The F-distribution assessment, also, showed that the model is acceptable.

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Appendix 1

A. **Individual Computations of** S_u^2 :

At N=1, $S_u^2 = (3.4216 - 3.1684)^2 + (2.9152 - 3.1684)^2 = 0.5064$

At N = 2, $S_u^2 = (3.9221 - 3.9829)^2 + (4.0437 - 3.9829)^2 = 0.0074$

At N = 3, $S_u^2 = (18.3405 - 18.1523)^2 + (17.9641 - 18.1523)^2 = 0.0708$

At N = 4, $S_u^2 = (11.8129 - 11.7651)^2 + (11.7173 - 11.7651)^2 = 0.0956$

At N = 5, $S_u^2 = (9.6897 - 9.3455)^2 + (9.0013 - 9.3455)^2 = 0.6884$

At N = 6, $S_u^2 = (9.9510 - 10.5763)^2 + (11.2016 - 10.5763)^2 = 1.2506$

At N = 7, $S_u^2 = (20.8617 - 21.4126)^2 + (21.9635 - 21.4126)^2 = 1.1018$

At N = 8, $S_u^2 = (21.9942 - 22.6983)^2 + (23.4024 - 22.6983)^2 = 1.4084$

B. Detailed Calculations of Coefficient Model Equation

$$b_o = \frac{1}{8}(3.1684+3.9829+18.1523+11.7651+9.3455+10.5763+21.4126+12.6983)$$

$$= 1/8\ (101.1014) = 12.6377$$

$$b_1 = \frac{1}{8}(3.1684 - 3.9829+18.1523 - 11.7651+9.3455 - 10.5763+21.4126 - 12.6983)$$

$$= 1/8\ (3.0562) = 0.3820$$

$$b_2 = \frac{1}{8}(3.1684+3.9829 - 18.1523 - 11.7651+9.3455+10.5763 - 21.4126 - 12.6983)$$

$$= 1/8\ (- 46.9552) = - 5.8694$$

$$b_3 = \frac{1}{8}(3.1684+3.9829+18.1523+11.7651 - 9.3455 - 10.5763 - 21.4126 - 12.6983)$$

$$= 1/8\ (- 26.964) = - 3.3705$$

$$b_{12} = \frac{1}{}(3.1684+3.9829 - 18.1523 -11.7651+9.3455+10.5763 - 21.4126 - 12.6983)$$

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$= 1/8\,(-7.1168) = -0.8896$

$b_{13} = \frac{1}{8}(3.1684 - 3.9829 + 18.1523 - 11.7651 - 9.3455 + 10.5763 - 21.4126 + 12.6983)$

$= 1/8\,(8.0892) = 1.0112$

$b_{23} = \frac{1}{8}(3.1684 + 3.9829 - 18.1523 - 11.7651 - 9.3455 - 10.5763 + 21.4126 + 12.6983)$

$= 1/8\,(1.4230) = 0.1779$

F. Detailed Calculation of '$\hat{y}_u$'

$\hat{y}_{u1} = 12.6377 + 0.3820 + 1.0112 + 0.1779 = 14.2088$
$\hat{y}_{u2} = 12.6377 - 0.3820 - 1.0112 + 0.1779 = 12.4224$
$\hat{y}_{u3} = 12.6377 + 0.3820 + 1.0112 - 0.1779 = 12.8532$
$\hat{y}_{u4} = 12.6377 - 0.3820 - 1.0112 - 0.1779 = 10.0668$
$\hat{y}_{u5} = 12.6377 + 0.3820 - 1.0112 - 0.1779 = 11.0666$
$\hat{y}_{u6} = 12.6377 - 0.3820 + 1.0112 - 0.1779 = 13.0890$
$\hat{y}_{u7} = 12.6377 + 0.3820 - 1.0112 + 0.1779 = 12.1864$
$\hat{y}_{u8} = 12.6377 - 0.3820 + 1.0112 + 0.1779 = 13.8268$

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