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Factorial Design on the Corrosion Inhibition Effects of Castor Seed Oil on Mild Steel

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ABSTRACT
2^3-Factorial Design on the corrosion inhibition effects of castor seed oil on mildsteel was performed in this study. Factorial experiments were conducted using the standard matrix developed by Frank Yates (the Yates Analysis), which incorporated eight (8) experimental runs. The experiments were also replicated, and the average values were obtained in each case. The Chochrain's distribution, **G** for the study was found to be 0.4968, which is less than the G_{Table} at 0.05 level of significance (0.6798), indicating that the homogeneity of variance for the process is acceptable. Also, the **F**-distribution (as computed) was found to be 7083.1130, which is greater than the F_{table} (4.46), indicating that the model is adequate, and as such acceptable. However, the model equation was found to be linear, indicating that the factors considered are in linear relationship with the response variable (the weight loss).
Keywords: Factorial Design, Corrosion Inhibition, Castor Seed Oil, Mild Steel.

INTRODUCTION
Factorial experiment is a procedure whose design consists of a number of factors, each with discrete possible values or levels. The experimental units of a factorial design take on all possible combinations of these levels across all such factors (Offurum and Chukwu, 2011). Factorial experiment allows studying the effects of each factor on the response variable, as well as the effects of interactions between the factors on the response variable. For vast majority of factorial experiments, each factor has only two levels. For instance, with two factors each taking two levels, a factorial experiment would have four treatment combinations in total, and this is referred to as a *'2x2 factorial design'*. If a number of combinations in a full factorial design is too high to be logically feasible,

a fractional factorial design may be done, in which some of the possible combinations (usually at least half) are omitted.

Hunter and Hunter (2005) reported that factorial designs were used in the 19th century by John Benneth Lawes and Joseph Henry Gilbert of the Rothamsted Experimental Station. The report went further to reveal also that Ronald Fisher (in 1926) was among those that argued that *complex* designs (such as factorial designs) were more efficient than studying one factor at a time. Fisher wrote (from the report) that "no aphorism is more frequently repeated in connection with field trials than that we must ask nature few questions, or, ideally, one question, at a time"; the writer is convinced that this view is wholly mistaken. *Nature,* he suggested, *will best respond to a logical and carefully thought-out questionnaire*. A factorial design allows the effect of several factors, and even interactions between them, to be determined with the same number of trials as are necessary to determine any one of the effects by itself, with the same degree of accuracy. Consequently, if there are *K-factors,* each at 2 levels, a full factorial design has 2^k number of runs; in this way, the number of experimental runs can be worked out for each number of factors at two level factorial considerations (Bali, 2004). In the present study, mild steel corrosion inhibition was considered, with castor seed oil as a locally sourced inhibitor, to assess its suitability as a formidable alternative.

MATERIALS AND METHOD

The basis for the factorial design, as it applies to the Sample (Castor Seed Oil, **CSO**), is given in *Table 1,* with Inhibitor Concentration (X_1), Temperature (X_2) and Time (X_3) as factors considered.

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

Factors	High Level(+1)	Low Level (-1)
Inhibitor Conc., X_1(g/l)	20	10
Temperature, X_2 (°C)	75	45
Time, X_3 (hr)	32	16

Corrosion experiments were conducted using the design matrix presented in *Table 2*. The 7th and 8th runs served as the control runs, and each run was replicated to obtain an average value of the response variable, $\mathbf{y_u}$ (*the weight loss*) as presented in *Table 3*.

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

The proposed model equation is given by *equation 1*.

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

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

Where:

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

$$S_u{}^2 = \frac{1}{\mathrm{n}-1} = \sum_k (\mathrm{y}_{uk} - \mathrm{y}_u)^2 \quad (3)$$

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

Thus,

$$\sum S_u{}^2 = 0.0270 + 0.2191 + 0.0109 + 0.0278 + 0.0513 + 0.3691 + 0.0311 + 0.0067 = \mathbf{0.7430}.$$

Then, $G = \frac{0.4968}{0.7430} = \mathbf{0.4968}$

But G_{table} (*0.05, 8, 1*), as contained in the *Statistical Table* = **0.6798** (Murray and Larry, 2011);

Where ***1*** = No. of replication; ***8***= No. of Experimental Runs; ***0.05***=Level of Significance.

Since G_{table} = **0.6798** > $G_{calculated}$ = **0.4968,** the Hypothesis for the homogeneity of Variance is Acceptable (Yordanov and Petkov, 2008).

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

$$S_{\mathcal{E}} = \frac{1}{8}(S_u^{\ 2}) = \frac{1}{8}(0.7430) = \mathbf{0.0929}$$

EVALUATION OF COEFFICIENTS OF THE MODEL EQUATION

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

$$\boldsymbol{b}_{\mathbf{i}} = \sum \boldsymbol{X}_{\mathbf{iu}}\bar{y}_{\mathbf{u}} \text{ where } \mathbf{i} = 1,2,3,4, \dots \dots \dots 8 \qquad (5)$$

Using *t-distribution* table to check the significance of the coefficients, it was observed that:

$\mathbf{t}_{table}$ (*8, 0.05*)**,** as presented in the *Statistical Table* **= 2.3061** (Murray and Larry, 2004)

Thus,

$$\boldsymbol{S_b} = \frac{\sqrt{(S_{\mathcal{E}}{}^2)}}{2N} = \frac{\sqrt{0.0929}}{2\ X\ 8} = \quad \mathbf{0.0190}$$

Then,

$(\mathbf{t}_{table})$ **.** $(\mathbf{S}_{b})$ = (2.3061) **.** (0.0190) = **0.0438**

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

$(\mathbf{t}_{table})$ **.** $(\mathbf{S}_{b})$ **= 0.0438 >** $\mathbf{b}_1$, $\mathbf{b}_3$, $\mathbf{b}_{12}$, $\mathbf{b}_{13}$ and $\mathbf{b}_{23}$; hence these coefficients are dropped from the Model (Yordanov and Petkov, 2008).

So, the ratified model equation is given as stated in *equation 6*.

$$\boldsymbol{y_u} = \boldsymbol{b_0} + \boldsymbol{b_2X_2}, \Rightarrow \boldsymbol{y_u} = \mathbf{0.0929} + \mathbf{0.0738}\boldsymbol{X_2} \qquad (6)$$

CHECKING FOR THE ADEQUACY OF MODEL

This is done by evaluating '$\hat{y}_{u,n}$' in all experimental runs for each of the variables in the Model Equation, 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*.

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

Then,

$$\Sigma(\hat{y} - y_u)^2 = 89.2874 + 17.0768 + 92.8737 + 165.9227 + 93.8302 + 119.9967 + 681.0482 + 714.0279 = \mathbf{1974.0635}$$

Then,

$$Q_L = 2 \times 1974.0635 = \mathbf{3948.127}$$

Also,

$\gamma_L = (N - d) = 8 - 2 = 6$; where, d = number of significant coefficients.

So,

$$S_L^2 = \frac{Q_L}{\gamma_L} = \frac{3948.127}{6} = \mathbf{658.0212}$$

Thus,

$$F = \frac{S_L^2}{S_\varepsilon^2} = \frac{658.0212}{0.0929} = \mathbf{7083.1130}$$

But F_{table} (0.05, 8, 2), as contained in *Statistical Table* = **4.46** (Murray and Larry, 2011);

Since $F_{calculated}$ = **7083.1130** > F_{table} = **4.46**, the model is said to be adequate.

RESULTS AND DISCUSION

The values of the variance, S_u^2 for the respective values of y_{mean} are presented in the *Table 3*, while the detailed calculations of S_u^2 are presented in *Appendix 1A*. Also, the values of the coefficients of the Model Equation, as computed using *equation 5*, are presented in *Table 4;* details of the computations are presented in *Appendix 1B*. Similarly, the values of standard frequency, 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 x_0	f_1 x_1	f_2 x_2	f_3 x_3	f_4 x_1x_2	f_5 x_1x_3	f_6 x_2x_3	y_1	y_2	y_u	S_u^2
1	+1	+1	+1	+1	+1	+1	+1	9.4996	9.7320	9.6158	0.0270
2	+1	-1	+1	+1	-1	-1	+1	3.9681	4.6301	4.2991	0.2191
3	+1	+1	-1	+1	-1	+1	-1	9.7301	9.5823	9.6562	0.0109
4	+1	-1	-1	+1	+1	-1	-1	13.0181	12.7823	12.9002	0.0278
5	+1	+1	+1	-1	+1	-1	-1	9.6932	10.0134	9.8533	0.0513
6	+1	-1	+1	-1	-1	+1	-1	10.6914	11.5506	11.1210	0.3691
7	+1	+1	-1	-1	-1	-1	+1	25.9913	26.2407	26.6160	0.7805
8	+1	-1	-1	-1	+1	+1	+1	26.7983	26.6825	26.7404	0.0067

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

Coefficient	b_0	b_1	b_2	b_3	b_{12}	b_{13}	b_{23}
Value	0.0929	-0.0628	0.0738	-0.0217	-0.0647	0.0183	-0.0227

Table 5: Squared Deviation of Variables in the Model Equation

Exp. Run	1	2	3	4	5	6	7	8
$\hat{y}$	0.1667	0.1667	0.0191	0.0191	0.1667	0.1667	0.0191	0.0191
y_u	9.6158	4.2991	9.6562	12.9002	9.8533	11.1210	26.1160	26.7404
$(\hat{y}-y_u)$	-9.4491	-4.1324	-9.6371	-12.8811	-9.6866	-10.9543	-26.0969	-26.7213
$(\hat{y}-y_u)^2$	89.2874	17.0767	92.8737	165.9227	93.8302	119.9967	681.0482	714.0279

The Chochrain's distribution, *G* for the study sample was found to be *0.4968*, whereas the G_{Table} (at 0.05 level of significance) is *0.6798*. Following from the documentations of Yordanov and Petkov (2008), it is deduced that the hypothesis for the homogeneity of variance is acceptable since $G_{Table} > G_{Calculated}$. Also, the ratified model equation for the sample is linear, which indicates that the factors considered are in linear relationship with the response variable (*the weight loss*).

Also, the $F_{calculated}$ = **7083.1130** was found to be greater than the F_{table} = **4.46**, indicating, that the model is adequate, and as such acceptable.

CONCLUSION

The factorial design study was basically used to assess the relationship between the factors considered (*Time, Temperature and Concentration*) and the response factor (*Weight Loss*). This culminated to the derivation of the optimal fit (*the model equation*) for the design. In this regard, the model equation was found to be linear as it possessed the features of equation of a straight line. Also, the hypothesis for the homogeneity of Variance is acceptable, following from the values of the Chochrain's Distribution (G), and the F-distribution assessment showed that the model is adequate, and as such is acceptable.

REFERNCES

Bali U. (2004). Application of Box-Wilson Experimental Design Method for the Photo degradation of Textile Dyestuff with UV/H_2O_2 Process; *Dyes and Pigments*; 60(8): 187-195.

Hunter J.S., Hunter W.G. (2005). Statistics for Experimenters: Design, Innovation and Discovery, 2nd Edition; *Wiley*, New-York.

Murray R. Spiegel and Larry J. Stephens (2011). Schaum's Statistics, Fourth Edition; *McGraw Hill*, New York.

Offurum J.C. and Chukwu M.M. (2011). Factorial Design for Adsorption of Solid Particles in Coal Effluent using Feather-derived Adsorbent; Continental Journal of Engineering Science; 6(3): 1-7.

Yordanov D. and Petkov P (2008). Investigation of Ethyl Esters of Fatty Acids as Corrosion Inhibitors; *Journal of the University of Chemical Technology and Metallurgy*; 43(4): 405-408.

APPENDIX 1

A. INDIVIDUAL COMPUTATIONS OF S_u^2 FOR CSO

At N=1, $S_u^2 = (9.4996 - 9.6158)^2 + (9.7320 - 9.6128)^2 =$ ***0.0270***

At N = 2, $S_u^2 = (3.9681 - 4.2991)^2 + (4.6301 - 4.2991)^2 =$ ***0.2191***

At N = 3, $S_u^2 = (9.7301 - 9.6562)^2 + (9.5823 - 9.6562)^2 =$ ***0.0109***

At N = 4, $S_u^2 = (13.0181 - 12.9002)^2 + (12.7823 - 12.9002)^2 =$ ***0.0278***

At N = 5, $S_u^2 = (9.6932 - 9.8533)^2 + (10.0134 - 9.8533)^2 =$ ***0.0513***

At N = 6, $S_u^2 = (10.6914 - 11.1210)^2 + (11.5506 - 11.1210)^2 =$ ***0.3691***

At N = 7, $S_u^2 = (25.9913 - 26.1160)^2 + (26.2407 - 26.1160)^2 =$ ***0.0311***

At N = 8, $S_u^2 = (26.7983 - 26.7404)^2 + (26.6825 - 26.7404)^2 =$ ***0.0067***

B. DETAILED CALCULATIONS OF COEFFICIENT MODEL EQUATION

$$b_0 = \frac{1}{8}(0.0270+0.2191+0.0109+0.0278+0.0513+0.3691+0.0311+0.0067)$$

$= 1/8\ (0.7430) =$ **0.0929**

$$b_1 = \frac{1}{8}(0.0270 - 0.2191+0.0109 - 0.0278+0.0513 - 0.3691+0.0311 - 0.0067)$$

$= 1/8\ (-0.5024) =$ **-0.0628**

$$b_2 = \frac{1}{8}(0.0270+0.2191 - 0.0109 - 0.0278+0.0513+0.3691- 0.0311 - 0.0067)$$

$= 1/8\ (0.5900) =$ **0.0738**

$$b_3 = \frac{1}{8}(0.0270+0.2191+0.0109+0.0278 - 0.0513 - 0.3691 - 0.0311 - 0.0067)$$

$= 1/8\ (-0.1134) =$ **-0.0217**

$$b_{12} = \frac{1}{8}(0.0270 - 0.2191 - 0.0109+0.0278+0.0513 - 0.3691 - 0.0311+0.0067)$$

$= 1/8\ (-0.5174) =$ **-0.0647**

$$b_{13} = \frac{1}{8}(0.0270 - 0.219+0.0109 - 0.0278 - 0.0513+0.3691 - 0.0311+0.0067)$$

$= 1/8\ (0.1466) =$ **0.0183**

$$b_{23} = \frac{1}{8}(0.0270+0.2191 - 0.0109 - 0.0278 - 0.0513 - 0.3691+0.0311+0.0067)$$

$= 1/8\ (-0.5024) =$ **-0.0227**

C. DETAILED CALCULATION OF '$\hat{y}_u$' FOR SAMPLE A (CSO)

$\hat{y}_1$ = 0.0929 + 0.0738 = **0.1667**

$\hat{y}_2$ = 0.0929 + 0.0738 = **0.1667**

$\hat{y}_3$ = 0.0929 – 0.0738 = **0.0191**

$\hat{y}_4$ = 0.0929 – 0.0738 = **0.0191**

$\hat{y}_5$ = 0.0929 + 0.0738 = **0.1667**

$\hat{y}_6$ = 0.0929 + 0.0738 = **0.1667**

$\hat{y}_7$ = 0.0929 – 0.0738 = **0.0191**

$\hat{y}_8$ = 0.0929 – 0.0738 = **0.0191**