

Development of Algae Guard Façade Paint with Statistical Modeling under Natural Phenomena

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Abstract

Algaecides are chemicals that cause serious health problems. Conventional paints contain algaecides to improve the algae resistance on the paint film. Present research has suggested an environmental friendly paint formulation that focuses on developing algae resistance without having algaecides. In this research, Algae growth on newly developed paint is modeled by incorporating dirt resistance of paint and natural phenomena including humidity, temperature and time respectively. The fitted Model revealed explained variation of 59.65% in the average algae growth, of which, Dirt Resistance, Humidity and temperature and some of their interactions play significant role in this variation. Model suggests that the proposed newly developed paint without algaecides is more resilient to algae growth and significantly decreased the average algae growth rate by 0.53% as compared to conventional paints. Keeping the effect of all other factors constant, if dirt resistance of paint (D_c value) increases by one percent, average algae growth decreases by 12.98%; when temperature increases by 1°C, average algae growth decreases by 22.4%; a positive unit change in the joint linear effect dirt resistance, temperature and humidity caused a decrease in average algae growth by 0.0031%. It was also observed that the individual effect of humidity variable was inversely related with average algae growth. However the combination of humidity and temperature, humidity and dirt resistance, humidity and time, and the quadratic effect of humidity were found to increase the average algae growth rate. The cubic effect of temperature variable by one degree centigrade resulted in decrease of average algae growth by 0.000907%.

Keywords:

Algaecides; Dirt; Humidity; Resilience; Temperature; Time

36 1. Introduction

37 Paint is a semi solid substance that is applied over a surface in the form of thin layer [1]. There are
38 two major functions of paint. One protection and the other is decoration. It has been observed that
39 fungi and bacteria usually develop on gloss paint films, whereas algae develop on water-based paints
40 [2]. Algae are the highly diversified group of microorganisms identified as microalgae. They have
41 been roughly enumerated as about ten million mostly microalgae [3]. The growth of microorganisms
42 in paint causes many problems such as degradation of paint films, blistering, flaking and
43 breakdown/cracking of the paint films [4]. Several cyanobacterial species causing different allergies
44 have been identified that could harm the brain or peripheral nervous system. The other harmful
45 effects are nerve ion-channel blocking, neuromuscular blockade, anti-acetyl cholinesterase activity,
46 anti-phosphate activity and protein synthesis inhibition [5]. Symptoms due to cyanobacteria intake
47 include abdominal pain, nausea, vomiting, diarrhea, sore throat, dry cough, headache, blistering of
48 the mouth, atypical pneumonia and elevated liver enzymes in the serum [6].

49 The most important chemical classes of algacides used in paints are Tributyltin (TBT), DIURON,
50 Carbendazim, Carbamates, Zinc pyrithione. TBT can induce histopathological effects and mortality
51 [7,8]. TBT pollution is of serious concern as it has led to collapse of whole populations of organisms
52 [9]. Diuron is a problematic water pollutant which has major impacts on human health and the
53 environment. The diuron is absorbed from the gastrointestinal and respiratory systems [10]. The
54 carbendazim is known to be carcinogenic, mutagenic and teratogenic in experimental animals and
55 animal cell cultures [11,12]. The carbamates inhibit cellular metabolism including energy, protein,
56 and nucleic acid metabolism, thereby, causing cell regression and death [13]. The zinc pyrithione was
57 found to be highly toxic to aquatic plants and animals [14] as it could inhibit cell growth [15,16].

58 It has been observed that anatase titanium dioxide could be used as a better preservative agent
59 against biodegradation compared to general biocides and also offers better result than some of the
60 conventional biocides [17]. It has also been observed that if a mixture of 75% anatase and 25% rutile
61 titanium dioxide is used then the mixture could serve as a better preservative agent against
62 biodegradation [18]. Another study shows that calcium carbonate could pose a negative impact on
63 photocatalytic inhibition activity against bacterial accumulation [19]. Zinc oxide used in the paint

64 formulations has been found to offer a unique property of self-cleaning of paint film in the presence
65 of UV light [20]. The zinc oxide nano particles show excellent antibacterial activity by breaking down
66 the microbial pollutants in the form of carbon dioxide and water in the presence of ultraviolet light
67 [21]. Zinc Oxide nano particles are found to be useful for preventing dirt accumulation over the
68 surface of the paint [22]. Dirt that is present on the façade painted surfaces promotes the growth of
69 microorganisms providing the required nutrients. This growth can occur even at a lower equilibrium
70 relative humidity (ERH) level [23-29]. Dirt collection index (D_c) indicates the tendency of a surface to
71 resist the accumulation of dirt and average dirt resistance. It is calculated by using standard ASTM
72 D 3719 – 00. Algae growth percentage is measured using the software Image J 1.50 i 'Wayne Rasband,
73 National Institute of Health USA'.

74 Multiple Linear Regression Modeling is an appropriate statistical tool to explore the significant effect
75 of independent variables and to predict the average response of the dependent variable. In case the
76 model consists of a large number of potential predictors it is reasonable to use the stepwise regression
77 procedures to determine the final model. In these techniques the inclusion of a variable is made one
78 by one, and if it is not significant then it is deleted. Moreover, if there are q variables then evaluate
79 only $q+1$ equations instead of 2^q equations.

80 There are two main types of these techniques; the forward selection method, and the backward
81 elimination method. The two methods are combined and refined in another selection procedure
82 which is named as the stepwise method. In the Forward selection technique, start with a regression
83 equation which contains no predictor variables but include a constant term only. The variable which
84 has the highest simple correlation with the dependent variable Y is included. The variable is
85 considered in the next step if the regression coefficient of the variable comes out to be significant and
86 differs from zero. Now another variable which must be highly correlated with the errors of the
87 aforementioned regression equation obtained in the first step, is included in the regression equation.
88 The test of significance is carried out again for the regression coefficient of the second variable taken
89 into the model. If this regression coefficient is found to be significant, continue search for a third in
90 the same manner. The procedure terminates until the last variable coming into the regression
91 equation is insignificant with respect to its regression coefficient otherwise all the variables are

92 incorporated in the final regression equation. The significance of the regression coefficient of the last
93 variable presented into the regression equation is decided by the usual t-test procedure from the latest
94 model.

95 In the backward elimination method, start with the full regression model and sequentially drop one
96 variable at a time. The criteria for dropping the variables is based on their contribution to the decline
97 of sum of squares of errors. The variable which has the minimum contribution is deleted. This step
98 actually equals to delete the variable having the smallest t-test value in the model. All the variables
99 are to be retained provided all the t-tests are significant. Contrary to this if there is at least one variable
100 having insignificant t-test, the process continues by ignoring the variable with t-test having the
101 smallest insignificance. The equation with the rest of $(q - 1)$ variables is refitted. On these variables
102 we apply t-tests for the new regression coefficients. The procedure ends either of the two ways; all
103 the t-tests are found to be significant or on the contrary the method removes all variables.

104 The stepwise method is essentially a forward selection procedure but with the added provision that
105 at each stage the possibility of deleting a variable, as in backward elimination, is considered. In this
106 procedure a variable that entered in the earlier stages of selection may be eliminated at later stages.
107 The calculations made for inclusion and deletion of variables are the same as forward selection and
108 backward elimination procedures. Often, different levels of significance are assumed for inclusion
109 and exclusion of variables from the equation [30].

110 The selection of the final model is made by using either of the above mentioned procedures and
111 comparing the models by using the criteria of adjusted R^2 -Adj. values, Mallows (1973) Cp-values,
112 RMSE (Root Mean Square Error) and AIC values. The introduction of dummy variables in regression
113 serves to compare the different levels of a categorical factor on the average³⁰. As per rule if there are
114 'k' categories 'k-1' dummy variables are formed to be included in the regression model. For each
115 dummy variable a regression equation/model is fitted and the intercept of the model indicates the
116 average value of the dependent variable for the particular level of the factor assuming the effects of
117 all other independent variables to be null [30].

118 The time factor, humidity, temperature and dirt accumulation are major sources of algae
119 accumulation on façade paints. The present work has been carried out to meet two main objectives.
120 First is to suggest a formulation of paint that could resist growth of algae without having algaecides.
121 This newly developed environment friendly paint must be at least equal in efficacy as those already
122 available formulations containing harmful algaecides. Second objective is to explore a linear or non-
123 linear relation which may be helpful in predicting the average algae growth rate on the basis of
124 predictors including Time (no. of days), D_c , Temperature and Humidity.

125 2. Material and Methods

126 2.1 Chemicals Used

127 The chemicals used in sample preparation are as follows:

- 128 a. Reverse osmosis treated water, TDS 0.01, hardness 4
- 129 b. Displex A-40, Dispersant, solution of an ammonium salt of an acrylic polymer in water,
130 BASF, Germany
- 131 c. Magnesium silicate, 65-micron particle size, Shaheen grinding, Pakistan
- 132 d. Acrysol tt 615, hydrophobically modified anionic thickener, Rohm and Haas, USA
- 133 e. Zinc oxide, Bruggemann chemical, Germany
- 134 f. KA-100, Anatase Titanium dioxide, Kimix, China
- 135 g. TiO₂ 2310, Rutile Titanium dioxide, Kronos titanium, USA
- 136 h. Propylene glycol, Dow, USA
- 137 i. Wacker 1306, emulsion of a polysiloxane modified with functional silicone resin, Wacker,
138 Germany
- 139 j. Displair cf-245, Mineral hydrocarbons Defoamer, Blackburn, UK
- 140 k. AMP-95, 95% , 2-Amino-2-Methyl-1-Propanol Solution, Angus, USA
- 141 l. PST-50A, Styrene acrylic copolymer emulsion, Organic Kimya, Turkey

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144 2.2 Preparation of Paint Sample

145 Mill base slurry was prepared in nano mill according to formulation as shown in Table 1. Output
 146 pneumatic pump pressure of nano mill was adjusted between 0.2 to 0.4 MPa. Revolution per minute
 147 (rpm) of nano mill shaft was adjusted at 2500. The output flow rate from nano mill was regulated at
 148 2 g/ sec. Fineness of Dispersion of the prepared slurry was determined by Hegman-Type Gage using
 149 the standard test ASTM-D 1210. It was observed that the particle size was 10 microns. Paint was
 150 prepared using nano slurry as per formula shown in Table 2 under conventional agitator. The
 151 revolution per minute (rpm) of agitator impeller was maintained at 1400.

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Table 1. Slurry composition

Serial No	Ingredients	Quantity (gram)
1	Water	27.16
2	Dispersant	0.84
3	AMP-95	0.60
4	Magnesium silicate	10.00
5	Zinc oxide	5.00
6	Anatase titanium dioxide	20.00
	Rutile titanium dioxide	7.00
7	Total	70.60

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Table 2. Paint composition

Serial No	Ingredients	Quantity (gram)
1	Nano mill slurry	70.60
2	Styrene acrylic	20.00
3	Propylene glycol	6.00
4	emulsion of a polysiloxane modified with functional silicone resin	2.00
	hydrophobically modified anionic thickener	0.84
6	Mineral hydrocarbons Defoamer	0.56
	Total	100.00

155 2.3 Experimental Observations

156 The Temperature (°C) and Humidity (%) were taken as recorded in Met office Lahore for the months
157 May, 2016 –April, 2017. The maximum and minimum daily temperature readings were taken to
158 measure the daily average temperature. The daily average temperatures were then used to compute
159 the average temperature per day by dividing their sum with the given number of days. Similarly, the
160 average humidity was also measured. These average values of Temperature and Humidity for the
161 respective number of days were computed and recorded against the given dates of the months as
162 mentioned in Table 3. Paint sample prepared was tested for algae growth. Four concrete slabs were
163 coated with developed paint and conventional paints. These slabs were placed in exterior conditions
164 at the experimental sight of Brighto Paint Pvt. Ltd. Pakistan. Due to administrative reasons D_c
165 readings and percentage surface area covered by algae was measured for every slab on the dates
166 mentioned in Table III. D_c readings were taken using ASTM D 3719 – 00, while Tape test was
167 performed on the slabs on the specific dates and the percentage surface area covered by algae was
168 measured for every slab by doing the image analysis of the microscopic pictures of the tapes. The
169 threshold was adjusted to detect the darker spots of algae. The percentage of darker areas was
170 measured using the software Image J 1.50 i 'Wayne Rasband, National Institute of Health USA'.

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Table 3. Summary of experimental results of Algal growth

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Date	Temperature °C	Humidity %	Newly Developed Paint		Conventional Paint A		Conventional Paint B		Conventional Paint C	
			D _c Value	Algae %	D _c Value	Algae %	D _c Value	Algae %	D _c Value	Algae %
23/05/2016	32.54	47.22	100.8	0.00	98.6	0.06	99.3	0.21	100.6	0.08
01/06/2016	32.96	43.33	98.7	0.05	98.7	0.75	97.7	0.46	98.1	0.58
11/06/2016	33.09	61.78	98.3	0.37	98.2	0.19	97	0.56	97.7	0.38
21/06/2016	33.14	66.44	98.66	0.08	98.24	0.68	96.48	0.04	97.7	0.54
01/07/2016	32.16	76.22	98.03	0.01	97.72	0.11	96.43	0.03	97.61	0.05
11/07/2016	30.47	79.22	98.14	0.18	98.04	0.25	96.35	0.35	97.31	0.71
21/07/2016	29.44	80.6	97.85	0.17	97.31	0.93	96.49	0.20	97.03	0.28
01/08/2016	29.87	78	97.91	0.03	97.47	0.04	96.11	1.39	97.08	0.05
11/08/2016	29.78	74	98.05	0.10	97.63	0.07	96.21	0.50	96.93	0.12
21/08/2016	30.64	84.5	97.83	4.22	97.68	1.27	96.1	0.95	96.6	2.60
01/09/2016	29.79	69.25	96.88	5.17	96.8	9.55	95.64	13.19	96.33	7.08
10/09/2016	30.93	70.3	96.62	0.41	96.55	0.48	95.46	0.52	96.2	1.28
21/09/2016	31	75	96.99	0.15	96.96	0.36	95.43	0.16	96.35	1.62
01/10/2016	28.07	70.44	96.16	0.17	96.09	0.61	94.3	0.93	95.62	0.45
11/10/2016	29.59	70.44	96.1	2.40	96	3.53	94.48	3.15	95.42	6.73
21/10/2016	25.61	76.2	96.49	1.12	96.38	2.02	94.36	1.62	95.49	0.51
01/11/2016	23.09	81.22	94.61	0.45	93.55	1.95	92	0.89	91.63	0.50
11/11/2016	20.44	73.56	95.85	0.78	95.37	2.85	93.54	6.92	94.22	1.52
21/11/2016	19.67	72.11	94.87	1.06	94.64	3.84	93.02	8.98	93.7	2.58
01/12/2016	18.84	86	94.08	0.85	93.97	0.74	92.92	0.45	93.84	1.68
11/12/2016	16.92	80.78	93.96	0.20	93.86	2.81	92.79	0.22	93.77	0.21
21/12/2016	14.6	87	93.42	0.34	93.29	0.40	91.64	0.08	92.2	0.55
02/01/2017	15.12	78	93.63	0.21	93.35	0.47	91.58	0.77	92.32	0.23
11/01/2017	14.39	84.22	93.53	0.51	93.3	0.40	91.67	0.56	92.25	0.43
21/01/2017	11.46	80.21	93.46	1.53	93.13	0.39	92.28	1.81	93.04	1.34
21/02/2017	16.47	62.38	93	0.70	92.95	0.87	91.27	9.96	91.94	0.77
01/03/2017	19.21	71.7	94.37	0.32	94.17	0.32	92.21	1.55	92.38	0.98
11/03/2017	18.53	58.65	94.31	0.60	94.23	2.86	91.94	0.71	92.11	0.40
11/04/2017	24.68	47.22	91.71	1.32	90.96	1.53	90.49	1.87	90.07	1.84

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175 Anderson Darling's test for Normality

176 Anderson Darling's test is used to test the Normality of a variable. A p-value of the statistic less than

177 0.05 leads to the rejection of the hypothesis of the data to follow the Normal distribution.

178 The Coefficient of Determination

179 The Criteria of R-square (R^2) is used for to explore the variation in the model explained by the
 180 independent variables. It is defined as $R^2 = \frac{ESS}{TSS}$, where ESS is Explained sum of squares and TSS
 181 denotes Total sum of squares. For the best model R^2 value must be large (as close to 1 as possible)³⁰.

182 The Adjusted R-square (R^2 -Adj)

183 R^2 -Adj is used for judging the goodness of fit and to compare models having different numbers of

184 predictor variables. It is defined as $R^2_{Adj} = 1 - \frac{SSE / (n-p-1)}{TSS / (n-1)}$, where SSE is Error sum of squares

185 and TSS denotes Total sum of squares. It is the unbiased estimate of population coefficient of
 186 determination. It is preferred over coefficient of determination R^2 as it gives the true change in
 187 explained variation due to addition of new explanatory variable³⁰.

188 **Mallows (1973) C_p -values:** The estimated values which are acquired from a fitted regression
 189 equation depending on a subset of predictors are usually biased. The mean square error of the
 190 estimated value is considered instead of the variance to compare the performance of an equation that
 191 is to be considered. The following formula is used to compute the standardized total mean squared
 192 error of prediction for the observed data,

$$193 \quad J_p = \frac{1}{\sigma^2} \sum_{i=1}^n \text{MSE}(\hat{y}_i) .$$

194 Where $\text{MSE}(\hat{y}_i)$ denotes the mean squared error of the i^{th} predicted value from a p -term equation,

195 and σ^2 is the random errors variance. To estimate J_p , Mallows (1973) used the statistic,

$$196 \quad C_p = \frac{\text{SSE}_p}{\hat{\sigma}^2} + (2p - n)$$

197 where $\hat{\sigma}^2$ is an estimated value of σ^2 and which is obtained from the linear model with the full set
 198 of q variables. The expected value of C_p , is p under the assumption of no bias in the fitted model
 199 containing p terms. Hence, the deviation of C_p , from p can be taken as a measure of bias. The C_p ,
 200 statistic therefore is a measure of the performance of the predictors transformed in standardized total
 201 mean square error of prediction for the observed data values without considering the actual model
 202 which is unknown. It includes both the components including bias and the variance. The subsets of
 203 predictors that give the minimum values of C_p , are taken as the anticipated subsets³⁰.

204 **The Standard Error of Regression**

205 The Standard Error of Regression or RMSE is given by

$$206 \quad s_e = \sqrt{MSE} = \sqrt{\frac{SSE}{n-p-1}} .$$

207 For the best suitable model, the Standard Error of Regression must be the smallest possible³⁰.

208 **Akaike (1973) Information Criteria (AIC)**

209 AIC is technique that is applied to rank and classify the various models relying upon their twin
 210 benchmarks of fit and simplicity. Two regression models for which AIC is not different by 2 are
 211 considered as equally suitable. If there are large difference in the values of AIC it would indicate that
 212 there is significant dissimilarity between the qualities of the two models. The model with the value
 213 of AIC to be minimum is considered as the finest³⁰. The formula for AIC when there is a p -term
 214 regression model, with a constant and $(p - 1)$ variables, is given by,

$$215 \quad AIC = n \ln(\hat{\sigma}^2) + 2p$$

$$\hat{\sigma}^2 = \frac{SSE}{n}$$

216

217

218 The Model

219 We use Linear Regression Model of order three to achieve the given objectives of the research
220 including second and third order interactions. The expression of full model is given as below:

$$\begin{aligned}
 221 \text{ ALGr=Y} &= \beta_0 + \beta_1(\text{NDP}) + \beta_2(\text{CN-1}) + \beta_3(\text{CN-2}) + \beta_4(\text{Dys}) + \beta_5(\text{Hm}) + \beta_6(\text{Tmp}) + \beta_7(\text{Drt}) + \\
 222 &+ \beta_8(\text{Dys}^2) + \beta_9(\text{Hm}^2) + \beta_{10}(\text{Tmp}^2) + \beta_{11}(\text{Drt}^2) + \beta_{12}(\text{Hm} * \text{Tmp}) + \beta_{13}(\text{Hm} * \text{Drt}) + \beta_{14}(\text{Tmp} * \text{Drt}) + \beta_{15}(\text{Dys}^3) + \\
 223 &\beta_{16}(\text{Hm}^3) + \beta_{17}(\text{Tmp}^3) + \beta_{18}(\text{Hm}^2 * \text{Drt}) + \beta_{19}(\text{NoD} * \text{Drt}) + \beta_{20}(\text{NoD} * \text{Hm}) + \beta_{21}(\text{Dys} * \text{Tmp}) + \beta_{22} \\
 224 &(\text{Dys} * \text{Hm}^2) + \beta_{23}(\text{Hm}^3) + \beta_{24}(\text{Tmp}^3) + \beta_{18}(\text{Drt}^3) + \beta_{25}(\text{Dys}^2 * \text{Hm}) + \beta_{26}(\text{Dys}^2 * \text{Tmp}) + \beta_{27}(\text{Dys}^2 * \text{Drt}) + \\
 225 &\beta_{28}(\text{Dys}^2 * \text{Tmp}) + \beta_{29}(\text{Dys}^2 * \text{Drt}) + \beta_{30}(\text{Dys} * \text{Hm} * \text{Tmp}) + \beta_{31}(\text{Dys} * \text{Hm} * \text{Drt}) + \beta_{32}(\text{Dys} * \text{Tmp} * \text{Drt}) + \\
 226 &\beta_{33}(\text{Dys} * \text{Drt}^2) + \beta_{34}(\text{Hm}^2 * \text{Tmp}) + \beta_{35}(\text{Hm}^2 * \text{Drt}) + \beta_{36}(\text{Hm} * \text{Tmp}^2) + \\
 227 &\beta_{37}(\text{Hm} * \text{Tmp} * \text{Drt}) + \beta_{38}(\text{Hm} * \text{Drt}^2) + \beta_{39}(\text{Tmp}^2 * \text{Drt}) + \beta_{40}(\text{Tmp} * \text{Drt}^2) + \epsilon \quad (\text{a})
 \end{aligned}$$

228 Where ALGr = Algae Surface Area in micro mm; Drt = Dirt Collection Index, Dc; Dys = Number of
229 days; Tmp = Temperature, °C; Hm = Humidity, %; NDP = 1, Dummy variable for Newly developed
230 paint, = 0, other paint; CN-1 = 1, Dummy variable for Conventional Paint A, = 0, other paint; CN-2 =
231 1, Dummy variable for Conventional Paint B, = 0, other paint and ϵ denotes the error term consisting
232 of unexplained variation in the dependent variable, the Algae growth rate.

233 The regression coefficients for each of the variables up to order three and along with their respective
234 interactions are denoted by $\beta_1, \beta_2, \dots, \beta_{40}$. Each of the given regression coefficients give the average
235 rate of change in Algae growth rate due to a unit value change in the respective variable. β_0 denotes
236 the intercept in the model. For each candidate model corresponding to the respective paint type there
237 will be different value of β_0 , which represents the average Algae growth rate when the given paint
238 is to be used after eliminating the effects of all other variables.

239 The data are analyzed using MINITAB version-17. The Stepwise method is used to achieve the final
240 model.

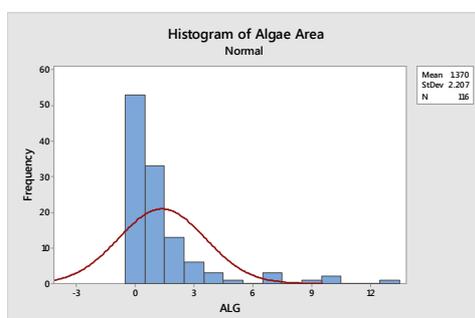
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244 2.4 Results of the Analysis

245 The distribution of response variable (Algae Area %) before commencing the regression analysis from
 246 Table 4 and the Histogram given in Fig. 1 was found to be positively skewed, as the



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Fig. 1. Histogram of Algae Area

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Table 4. Statistics of Algae Area

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Mean	1.37
Standard Deviation	2.207
Anderson Darling Statistic value	16.073
P-value	<0.005

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255 Anderson Darling's test for Normality showed a p-value less than 0.05. The Logarithmic
 256 transformation was used to make the distribution of the variable Normal. The transformed variable
 257 is named as new Algae Area and results of transformed variable is given in Table V and Fig. 2a and
 258 2b. Anderson Darling's test for Normality showed a p-value greater than 0.05 leading to the
 259 acceptance of the hypothesis of the data to follow the Normal distribution and from Fig 2 and 3.

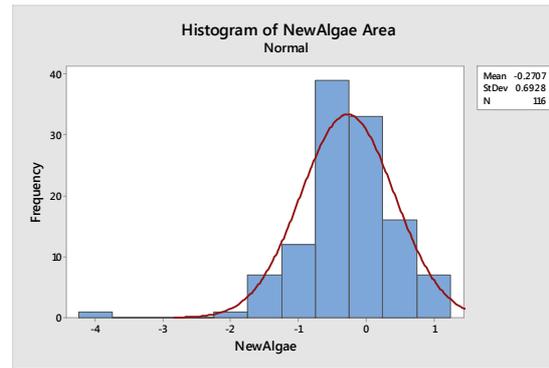
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Table 5. Statistics of new Algae Area

Mean	-0.2707
Standard Deviation	0.6928
Anderson Darling Statistic value	1.0838
P-value	0.01



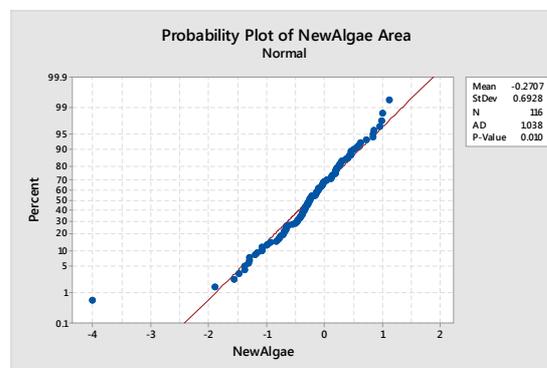
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Fig. 2. Histogram of new Algae area

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Fig. 3. Probability plot of new Algae area

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270 The Stepwise selection procedure applied on full regression model yielded the results of the final
 271 model to be selected either from step 15,16 or 17, are given in Table VI. The results of R-square,
 272 Adjusted R-square, Mallows Cp, Standard error of regression and AIC were used for choosing the
 273 best suitable model. Minitab was instructed to include dummy variables at each step as the purpose
 274 of study was to predict the Average Algae growth rate on the basis of models for each of the
 275 competitive paint type. Table VII gives the ANOVA for the final model and the expressions of fitted
 276 regression equations are also given below.

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Table 6. Step wise selection procedure results

		Step 15	Step 16		Step 17	
	Coefficients	P- valu e	Coefficient s	P- valu e	Coefficient s	P- valu e
Constant	1203		1234		1603	
NDP	-0.526	0.001	-0.53	0.001	-0.529	0.001
CN-1	-0.157	0.282	-0.159	0.271	-0.159	0.269
CN-2	0.179	0.228	0.178	0.227	0.186	0.205
Dys	0.053	0.788	-0.003	0.981	-0.004	0.966
Hm	-27.53	0.001	-27.04	0.001	-34.39	0.001
Tmp	-20.7	0.047	-22.4	0.014	-31.4	0.005
Dys*Hm	-0.00338	0.232	-0.00369	0.166	-0.00435	0.107
Dys*Tmp	0.00257	0.035	0.00277	0.009	0.00436	0.005
Hm*Tmp	0.22	0.079	0.232	0.054	0.353	0.017
Dys*Hm*Tmp						
Tmp*Tmp	0.0787	0.004	0.0814	0.002	0.0864	0.001
DRT	-12.67	0.002	-12.98	0.001	-16.37	0
Tmp*Drt	0.205	0.047	0.2214	0.014	0.3	0.005
Tmp*Tmp*DRT						
Hm*DRT	0.3074	0	0.3025	0	0.3712	0
Hm*Hm	0.1455	0.004	0.1386	0.002	0.1729	0.001
Dys*Hm*Hm	0.000033	0.123	0.000036	0.074	0.000034	0.092
Hm*Hm*Tmp	0.000596	0.007	0.000592	0.007	0.000492	0.032
Hm*Hm*DRT	-0.001708	0.001	-0.001639	0	-0.001948	0
Tmp*Tmp*Tm P	-0.000866	0.036	-0.000907	0.021	-0.000844	0.032
Dys*Dys	0.000047	0.417	0.000061	0.115	-0.000157	0.317
Dys*DRT	-0.00058	0.741				
Dys*Dys*DRT						
Hm*Tmp*DRT	-0.00299	0.016	-0.0031	0.009	-0.00416	0.003
Dys*Dys*Hm					0.000004	0.154

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Table 6. Step wise selection procedure results (contd.)

	Step 15	Statistics	Step 16	Step 17
Standard Error	0.491774		0.489465	0.486741
R-sq	58.81%		58.77%	59.65%
R-sq(adj)	49.61%		50.09%	50.64%
R-sq(pred)	31.55%		32.80%	32.83%
Mallows'				
Cp	23.21		21.32	21.27

289

290

Table 7. ANOVA

Source	Degree of Freedom	Seq SS	Contribution	Adj SS	Adj MS	F	P-Value	Value
Regression	21	32.9269	59.65%	32.9269	1.56795	6.62	0	
Dys	1	8.7024	15.77%	0.0004	0.00043	0	0.966	
Hm	1	1.5116	2.74%	3.0528	3.05282	12.89	0.001	
Tmp	1	2.7377	4.96%	1.9725	1.97249	8.33	0.005	
DRT	1	1.3884	2.52%	3.0968	3.09679	13.07	0	
NDP	1	1.9468	3.53%	2.7067	2.70665	11.42	0.001	
CN-1	1	0.0368	0.07%	0.2928	0.29277	1.24	0.269	
CN-2	1	0.0162	0.03%	0.3854	0.38536	1.63	0.205	
Dys*Dys	1	3.2059	5.81%	0.2393	0.23929	1.01	0.317	
Hm*Hm	1	0.1791	0.32%	2.8798	2.87981	12.16	0.001	
Tmp*Tmp	1	0.001	0.00%	2.6893	2.68929	11.35	0.001	
Dys*Hm	1	0.059	0.11%	0.6287	0.62871	2.65	0.107	
Dys*Tmp	1	0.0243	0.04%	1.9548	1.95478	8.25	0.005	
Hm*Tmp	1	0.1876	0.34%	1.3982	1.39818	5.9	0.017	
Hm*DRT	1	5.0513	9.15%	3.6732	3.67321	15.5	0	
Tmp*DRT	1	0.0538	0.10%	1.987	1.98701	8.39	0.005	
Tmp*Tmp*Tmp	1	0.0005	0.00%	1.12	1.12393	4.74	0.032	
Dys*Dys*Hm	1	0.0861	0.16%	0.4896	0.48958	2.07	0.154	
Dys*Hm*Hm	1	1.5526	2.81%	0.6873	0.68735	2.9	0.092	
Hm*Hm*Tmp	1	2.2998	4.17%	1.1293	1.12934	4.77	0.032	
Hm*Hm*DRT	1	1.7178	3.11%	3.8722	3.87216	16.34	0	
Hm*Tmp*DRT	1	2.168	3.93%	2.168	2.16796	9.15	0.003	

Error	94	22.270 1	40.35%	22.270 1	0.23692
Total	115	55.197 1	100.00%		

291 The Regression equation for NDP is given by,
 292 $\text{NewAlgae} = 1603 - 0.004 \text{ Dys} - 34.39 \text{ Hm} - 31.4 \text{ Tmp} - 16.37 \text{ DRT} - 0.000157 \text{ Dys} * \text{Dys} + 0.1729$
 293 $\text{Hm} * \text{Hm} + 0.0864 \text{ Tmp} * \text{Tmp} - 0.00435 \text{ Dys} * \text{Hm} + 0.00436 \text{ Dys} * \text{Tmp} + 0.353 \text{ Hm} * \text{Tmp} + 0.3712$
 294 $\text{Hm} * \text{DRT} + 0.300 \text{ Tmp} * \text{DRT} - 0.000844 \text{ Tmp} * \text{Tmp} * \text{Tmp} + 0.000004 \text{ Dys} * \text{Dys} * \text{Hm} + 0.000034$
 295 $\text{Dys} * \text{Hm} * \text{Hm} + 0.000492 \text{ Hm} * \text{Hm} * \text{Tmp}$
 296 $- 0.001948 \text{ Hm} * \text{Hm} * \text{DRT} - 0.00416 \text{ Hm} * \text{Tmp} * \text{DRT}$

297

298 2.5 Conclusions

299

300 Keeping the effect of all other factors constant the use of newly developed paint significantly
 301 decreases the average algae growth rate by 0.53%. The variation in algae growth explained by this
 302 variable is 3.53%. Keeping the effect of all other factors constant, if humidity increases by one percent,
 303 algae growth will decrease by 27.04%. The variation in algae growth explained by the humidity
 304 variable is 2.74%. Keeping the effect of all other factors constant, if temperature increases by one
 305 degree centigrade, algae growth will decrease by 22.4%. The variation in algae growth explained by
 306 the temperature variable is 4.96%. Keeping the effect of all other factors constant, if dirt resistance
 307 of a paint increases by one percent, algae growth will decrease by 12.98%. The variation in algae
 308 growth explained by the dirt resistance variable is 2.52%. Keeping the effect of all other factors
 309 constant, if there is a positive unit change in the joint effect of time and temperature, it would result
 310 in increase in algae growth by 0.0027 %. The variation in algae growth explained by the joint effect of
 311 these variable is 0.04%. Keeping the effect of all other factors constant, if there is a positive unit change
 312 in the joint effect of humidity and temperature it would result in an increase in algae growth by
 313 0.232%. The variation in algae growth explained by the joint effect of these variables is 0.34%. Keeping
 314 the effect of all other factors constant, if there is a positive unit change in the joint effect of dirt
 315 resistance and temperature it would result in an increase in algae growth by 0.2214%. The variation
 316 in algae growth explained by the joint effect of these variable is 0.10%. Keeping the effect of all other

317 factors constant, if there is a positive unit change in the joint effect of dirt resistance and humidity,
318 algae growth will increase by 0.3025 units. The variation in algae growth explained by the joint effect
319 of these variables is 9.15%. Keeping the effect of all other factors constant, if there is an increase in the
320 quadratic effect of humidity, algae growth will increase by 0.1386 units. The variation in algae growth
321 explained by this quadratic effect is 0.32%. Keeping the effect of all other factors constant, if there is
322 a positive unit change in the joint linear effect of time and quadratic effect of humidity, algae growth
323 will increase by 0.000036 units. The variation in algae growth explained by this interaction effect is
324 0.16%. Keeping the effect of all other factors constant, if there is a positive unit change in the joint
325 linear effect of temperature and quadratic effect of humidity, algae growth will increase by 0.000592
326 units. The variation in algae growth explained by this interaction effect is 4.17%. Keeping the effect
327 of all other factors constant, if there is a positive unit change in the joint of dirt resistance and
328 quadratic effect of humidity, algae growth will decrease by 0.001639 units. The variation in algae
329 growth explained by this interaction effect is 3.11%. Keeping the effect of all other factors constant, if
330 there is a positive unit change in the joint linear effect dirt resistance, temperature and humidity,
331 algae growth will decrease by 0.0031 units. The variation in algae growth explained by this interaction
332 effect of the three variables is 3.93%. Keeping the effect of all other factors constant, the cubic effect
333 of temperature variable by one degree centigrade, will result in decrease of algae growth by
334 0.000907%.

335

336 The individual effect of Time (No of days) came out to be insignificant, though its contribution
337 towards the algae growth was 15.77%. However, when time is incorporated with temperature, it had
338 significant effect on algae growth rate. Similarly, when time variable is mixed with the quadratic
339 effect of humidity variable it significantly affected the algae growth rate. The competitor paints 1,2
340 and 3 were found to be insignificantly affecting the algae growth rate. However, the newly developed
341 paint had a significant effect on the reduction on average algae growth rate. The individual effect of
342 humidity variable was inversely related with average algae growth while the combination of
343 humidity and temperature, humidity and dirt resistance, humidity and time, and the quadratic effect
344 of humidity were found to increase the average algae growth rate.

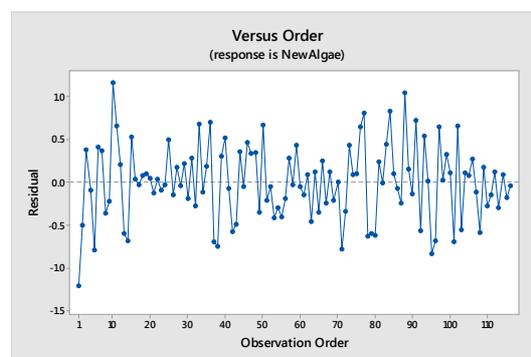
345 On the basis of above discussion, the fitted regression model formed can be considered as the best
346 suitable model. With the help of this model, algae growth could be predicted for given values of the
347 independent variables. For example, if number of days are 40, humidity 45%, temperature 30°C and
348 dirt resistance 98, then Algae growth %age will be:

349 New Algae = -2.7997

350 Algae growth = anti log (-2.7997) = 0.002%

351 Assumptions of the model

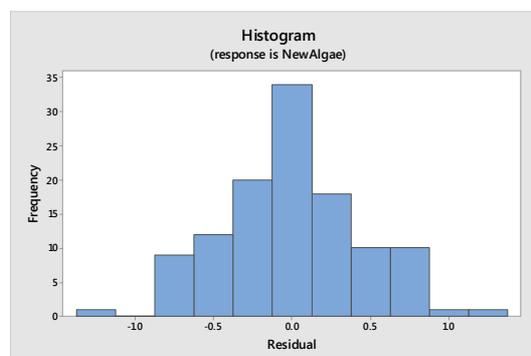
352 The structure less plot of residual over time Fig.4, and the value of Durbin-Watson Statistic =
353 1.97714 indicates that there is no autocorrelation among errors and hence they are independently
354 distributed. Refer to Fig. 5 the Histogram, Fig. 6. the Normal probability plot and the p-value of
355 Anderson Darling test statistic which is 0.724, indicate that the errors are normally distributed.
356 Refer to Fig. 7, the structure less plot of residuals over fitted values verifies the assumption of
357 homoscedasticity of errors. There were no influential observations found in the data set.



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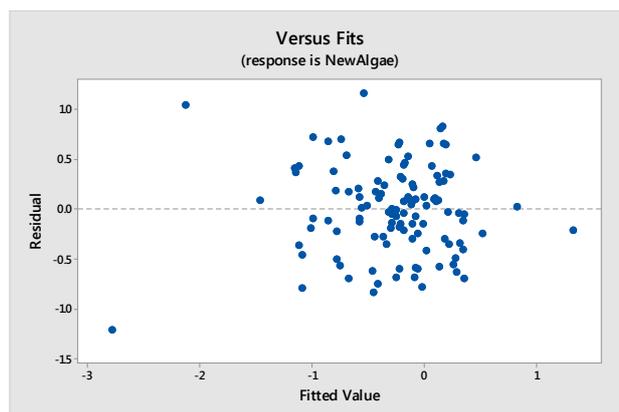
Fig. 4. Residuals versus observation order



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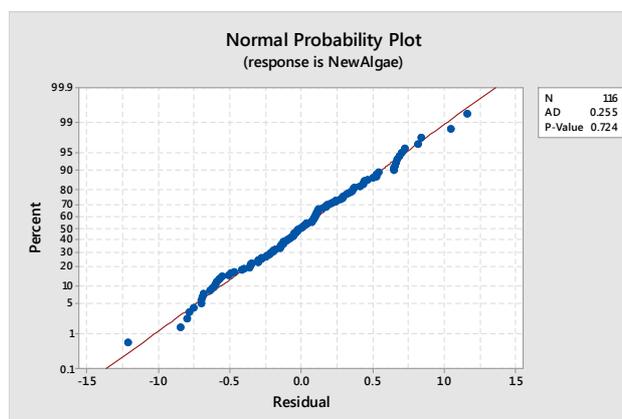
Fig. 5. Histogram of residuals



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Fig. 6. Normal probability plot



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Fig. 7. Residual versus fitted values

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