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Mathematical Model for Predicting the Water Absorption of Crude Oil Contaminated Concretes

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ABSTRACT
A sizeable proportion of concrete components used for constructions within mild to severe areas of crude oil polluted environments within the Niger Delta area of Nigeria is contaminated with crude oil to varying ranges. This work tries to understudy the water absorption behaviourof the concretes to crude oil. In this work, crude oil was used as a fifth ingredient of concrete mix which replaced 5% to 20% of the w/c. The four other component were cement, sand, granite, and water. A designed mix ratio of 1:2:4 with w/c of 0.5 was utilized as the initial component mix design. Scheffe's simplex theory was used for the five mix ratios in a {5,2} experimental design. This gave rise to ten additional mix ratios and fifteen other additional mix ratios were generated for control purposes. These thirty concrete mix ratios were subjected to laboratory experiments to determine the water absorption at 28 days. The results of the first fifteen water absorption were used for the calibration of the model constant coefficients, while the results from the second fifteen were used as control using Scheffe's simplex lattice design. A mathematical regression model was derived from the results, with which the water absorptions were predicted. The derived model was subjected to a two-tailed t-test with 5% significance, which ascertained the model to be adequate with an R2 value of 0.8461. The study revealed that crude oil presence in a concrete drastically reduces its water absorption propertiesas 3.7% absorption was noticed in concretes without crude oil and 0.83% absorption was noticed in concrete with 20% presence of crude oil.

Keywords: *Crude oil, Scheffe's simplex lattice design, Water absorption.*

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I. INTRODUCTION

Crude oil contamination has been one of the global environmental concerns despite the facts that crude oil has remain one of the blessings of nature that acts as the source energy for the daily operations of humans, hence a viable source of income to the economy amidst its several other benefits. Concrete is a substance used for building which is made by mixing together cement, sand, granite, and water. Structural concrete is a special type of concrete that is capable of carrying a structural load or forming an integral part of a structure. According to [1], concrete had been used as an ad hoc construction material until 1919 when Duff Abram found the water-cement ratio law, which changed led to concrete quality control through scientific procedures. Crude oil contaminated concretes are normal concrete with traces of crude oil in its mix and or cured in crude oil contaminated environment. Most have actually argued that no sane constructor could allow the presence the of crude oil within its concrete, but in practical scenario, this is false considering that traces of crude oil presence are actually found within most of the concrete component especially within crude oil polluted environments. Hence, crude oil interaction with concrete can either be within the concrete mix or external interaction during curing which the practical reality is the submerging of concrete structures with crude contaminated water within areas of mild or severe crude oil pollution.

These have generated a lot of concern among researchers to understudy both the internal and external interaction of concretes with crude oil as to whether to completely discard it or to optimize its resourcefulness to concrete production.

Works by [2] and [3] actually indicated that crude oil is aggressive to concrete and that the presence of crude oil in concrete actually influences the properties of the concrete. There is therefore the need to develop models that can predict the water absorption of concretes in interaction with crude oil. Such models can also be used to under study the component interactions. In this work, mixture experiment models for predicting the water absorption of crude oil contaminated concrete cured in crude oil contaminated environment were developed using Scheffe's augmented simplex lattice design [4].

II. MIXTURE EXPERIMENTS AND SCHEFFE'S MODEL EQUATION

A mixture experiment is one in which the response is assumed to be dependent on the relative proportions of the constituent materials and not on their total amount [7]. For such experiments, there are two basic requirements that must be satisfied namely; the sum of the proportions of the constituents must add up to one and none of the constituents will have a negative value [6]. Scheffe's simplex lattice design is actually one of the many mixture experiment model forms that exist. [4] invented an empirical model in form of the polynomial equation. The equation for such designs, which for a second degree polynomial for {*q*, *m*} is given as:

$$Y = \sum_{1\le i\le q} \beta_i X_i + \sum_{1\le i\le j\le q} \beta_{ij} X_i X_j \qquad (1)$$

Y is the response function and X_i (i= 1 to q) is the proportion of component *i*in the mixture. The second degree polynomial is the most commonly used polynomial to fitting mixture experiment data. The component mixture equation (1) is expressed as:

$$Y_{ij}= 4Y_i - 2Y_i - 2Y_j \qquad (2)$$

Therefore, for a five component mixture {*5*, *2*}, equation (2) is expressed as:

$$Y = \beta_1x_1 + \beta_2x_2 + \beta_3 x_3 + \beta_4x_4 + \beta_5x_5 + \beta_{12}x_1x_2 + \beta_{13}x_1x_3 + \beta_{14}x_1x_4 + \beta_{15}x_1x_5 + \beta_{23}x_2x_3 + \beta_{24}x_2x_4 + \beta_{25}x_2x_5 + \beta_{34}x_3x_4 + \beta_{35}x_3x_5 + \beta_{45} x_4x_5 \qquad (3)$$

The estimated coefficients in equation (1) were determined after a mixture regression analysis of the experimental data. The canonical polynomial has fewer terms than the standard polynomial and is often referred to as the {*q*, *m*} polynomial; *m* being the degree of the polynomial. [5] and [6] are among other researchers that have also worked on Scheffes simplex theory.

III. MATERIALS

Water, Cement, Sand, granite and crude oil are the materials used for the concrete production. Potable water was used. Dangote brand of Ordinary Portland cement of 42.5 grade which conforms to NIS: 444 (2003) was used. The sand with a specific gravity of 2.68 and coefficient of uniformity of 1.49. The corresponding values for the granite of 10mm size are 2.70 and 1.53. Bonny light Crude oil was gotten from Rivers State, Nigeria.

IV. EXPERIMENTAL DESIGN

An augmented {5, 2} Scheffe's simplex lattice design with 15 points was used as represented in figure (1) and (2) below. The number of components is 5 and a second degree polynomial was used in designing the experiments. That is, q = 5 and n = 2. An initial mix design was done which thereafter, the first five concrete mix ratios derived from different percentages of contaminations (0% - 5%) which represents the main components are presented as S: [0.5, 1, 0, 2, 4]; [0.475, 1, 0.025, 2, 4]; [0.45, 1, 0.05, 2, 4]; [0.425, 1, 0.075, 2, 4]; [0.40, 1, 0.10, 2, 4]. Their corresponding pseudo components are given as X: [1, 0, 0, 0, 0]; [0, 1, 0, 0, 0]; [0, 0, 1, 0, 0]; [0, 0, 0, 1, 0]; [0, 0, 0, 0, 1]. And centre points of the pseudo components are represented as: X_{12} = [0.5 0.5 0 0 0]; X13 = [0.5 0 0.5 0 0];
X_{14} = [0.5 0 0 0.5 0]; X15 = [0.5 0 0 0 0.5]; X_{23} = [0 0.5 0.5 0 0]; X24 = [0 0.5 0 0.5 0]; X_{25} = [0 0.5 0 0 0.5];
X34 = [0 0 0.5 0.5 0]; X_{35} = [0 0 0.5 0 0.5]; X45 = [0 0 0 0.5 0.5].
[4] stipulates, Sij = XS_i (4)
Substituting gives the corresponding centre point values for the main components.

Similarly, this process is repeated for an additional 15 (control) points that was used for the verification of the formulated model. All were then subjected to experimental proceedings in order to determine their various responses which were used in the formulation of the model equation. The test for absorption was made in accordance to [8]when the age of the concrete is 28 days to 32 days, which means that drying of the specimens began at an age of 24 days to 28 days. Concrete cubes of 150mm x 150mm x 150mm were used. The measured absorption of each specimen was calculated as the increase in mass resulting from immersion expressed as a percentage of the mass of the dry specimen.
The regular pentagons for the pseudo components and corresponding actual components are given in figures (1) and (2) respectively.

V. RESULTS

Table 1 shows the pseudo components, results of the water absorption tests and result from the Scheffes model.

Model equation for the water absorption

The coefficients of polynomial from table (1), eq. (2) are substituted into eq. (3) to give the resultant model equation:

$$Y=3.70x_1+1.23x_2+1.04x_3+0.83x_4+0.54x_5-5.32x_1x_3-4.33x_1x_4-4.43x_1x_5+0.19x_2x_3-0.04x_2x_4+0.20x_2x_5+0.16x_3x_5 \qquad (5)$$

Eq. (5) above is the mathematical model to predict the 28 dayswater absorption of concrete contaminated with crude oil and cured at portable water medium.

Test of Adequacy of the Model

The coefficients of polynomial from table (4),
A two-tailed student t-test was carried out at 95% confidence level.
Let D be difference between the experimental and predicted responses
The mean of the difference,

$$D_a = \frac{1}{n}\sum_{i=1}^{n}(D_i) \quad (7)$$

The variance of the difference,

$$S^2 = \frac{1}{n-1}\sum_{i=1}^{n}(D - D_a)_i^2 \quad (8)$$

Where n = number of observations with degree of freedom n – 1.

$$T_{calc} = \frac{D_a\sqrt{n}}{S} \quad (9)$$

From the Table t-test table, $T_{(0.95,14)} = 2.145$. Also, from Table (2) $T_{calculated} < T_{(0.975,14)} = 0.342$, and lies between -2.145 and 2.145, therefore there is no significant difference between the experimental and predicted responses, H0 is accepted, and Ha is rejected. The model is confirmed to be adequate. Fig.2 shows the scatter plot between the experimental and predicted responses. From fig 4, the R^2 value of 0.8461 indicates that the experimental results are highly correlated to the predicted results which is an additional confirmation that the mode is fit and adequate.

VI. CONCLUSION AND RECOMMENDATION

A mathematical model for the prediction of the water absorption of contaminated crude oil cured in portable water medium was developed in this work. A two-tailed t-test was carried out at 5% significance level, which confirmed the adequacy of the derived model with an R2value of 0.8461. The use of these models will greatly help to ensure sustainability in production within crude oil contaminated region.

Table 1 Pseudo components, Water absorption tests results and Scheffes model results

Pseudo Components						
w-c ratio	**cement**	**crude oil**	**sand**	**granite**		
X1	**X2**	**X3**	**X4**	**X5**	**Y_{exp}**	**Y_{pred}**
1	0	0	0	0	3.700	3.700
0	1	0	0	0	1.230	1.230
0	0	1	0	0	1.040	1.040
0	0	0	1	0	0.830	0.830
0	0	0	0	1	0.540	0.540
0.5	0.5	0	0	0	2.465	2.465
0.5	0	0.5	0	0	1.040	1.040
0.5	0	0	0.5	0	1.183	1.183
0.5	0	0	0	0.5	1.014	1.014
0	0.5	0.5	0	0	1.183	1.183
0	0.5	0	0.5	0	1.040	1.040
0	0.5	0	0	0.5	0.935	0.935
0	0	0.5	0.5	0	0.935	0.935
0	0	0.5	0	0.5	0.830	0.830
0	0	0	0.5	0.5	0.685	0.685
Control						
0.49	0.3	0.1	0	0.11	1.378	1.860
0.25	0	0.3	0.15	0.3	0.988	0.645
0.1	0.15	0.2	0.3	0.25	0.946	0.823
0.15	0.21	0	0.15	0.49	0.910	0.802
0	0.24	0.11	0.49	0.16	0.920	0.923
0.49	0.31	0.09	0.11	0	1.675	1.918
0.21	0.32	0.12	0.22	0.13	1.089	1.114
0	0.27	0.22	0.17	0.34	0.918	0.929
0.27	0.1	0.31	0.29	0.03	1.095	0.890
0.49	0.13	0.21	0.17	0	1.219	1.430
0	0.19	0.49	0.11	0.21	0.969	0.991
0.19	0.09	0.26	0.37	0.09	1.023	0.808
0.1	0.21	0.13	0.21	0.35	0.935	0.841

0.11	0.2	0	0.2	0.49	0.880	0.771
0.15	0.28	0.46	0.06	0.05	1.120	1.047

Table 2 Statistical t- test for 28 days water absorption of crude contaminated concrete

Sample	Flexural Strength		t test	t test	t test
	Yexp	Ypredict	D=Yex-Ypred	Da - D	(Da - D)^2
C1	1.3782	1.8602725	-0.4820725	0.5002478	0.25024786
C2	0.9875	0.64465	0.34285	-0.3246747	0.10541366
C3	0.9455	0.822575	0.122925	-0.1047497	0.0109725
C4	0.9098	0.8015775	0.1082225	-0.0900472	0.0081085
C5	0.9203	0.922916	-0.002616	0.0207913	0.00043228
C6	1.6746	1.917866	-0.243266	0.2614413	0.06835155
C7	1.0894	1.1142155	-0.0248155	0.0429908	0.00184821
C8	0.9182	0.92905	-0.01085	0.0290253	0.00084247
C9	1.0951	0.8902725	0.2048275	-0.1866522	0.03483904
C10	1.2186	1.430354	-0.211754	0.2299293	0.05286748
C11	0.9686	0.990969	-0.022369	0.0405443	0.00164384
C12	1.0232	0.8080675	0.2151325	-0.1969572	0.03879214
C13	0.935	0.840766	0.094234	-0.0760587	0.00578493
C14	0.8804	0.7710325	0.1093675	-0.0911922	0.00831602
C15	1.1198	1.0469865	0.0728135	-0.0546382	0.00298533
TOTAL			0.2726295		0.59144581
AVE, Da			0.0181753		
S2=	0.0422461				
S=	0.2055386				
Tcalc=	0.3424788				
T(0.975,14)		2.145			

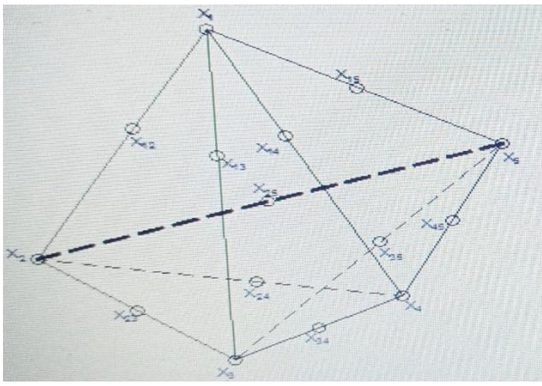

Figure 1: Simplex lattice for pseudo components

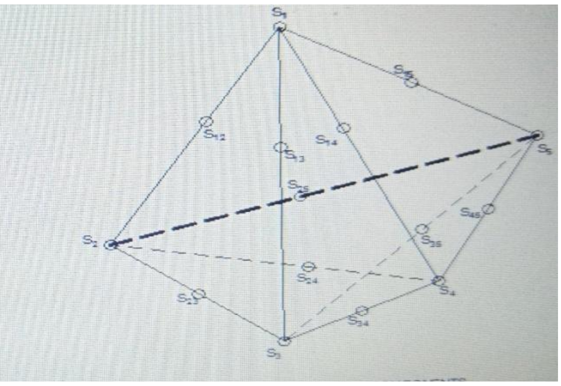

Figure 2: Simplex lattice for actual components

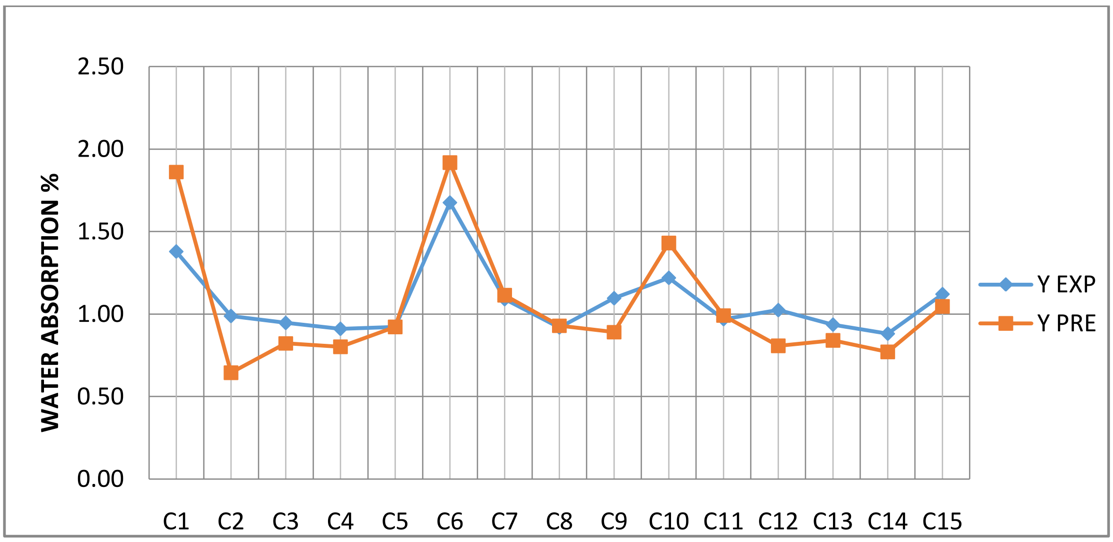

Figure 2: Comparison between Experimental and Predicted 28days water absorption

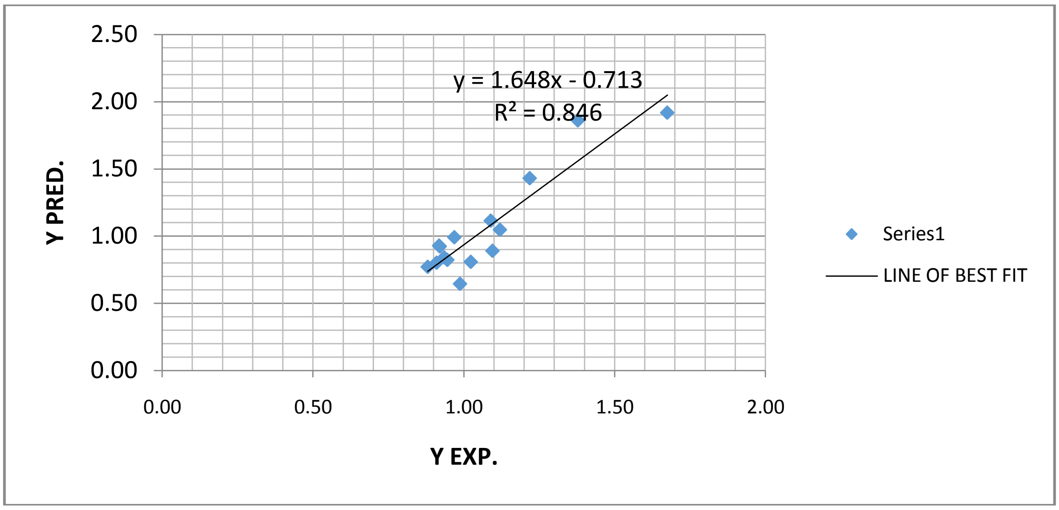

Figure 3: Scatterplot of Predicted vs. Experimental 28days Water absorption

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