FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA

SCHOOL OF ENGINEERING AND ENGINEERING TECHNOLOGY

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THEME: DECAY IN INFRASTRUCTURE – A CHALLENGE TO SCIENCE AND ENGINEERING RESEARCH IN REALISING VISION 20 – 2020

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APPLICATION OF FACTORIAL DESIGN TO THE PRODUCTION OF TEXCOAT PAINT

by

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ABSTRACT.

This research paper is centered on application of factorial design in the production of texcoat paint. Three varying factors Calcium carbonate (x_1), polyvinyl acetate (x_2) and Titanium dioxide (x_3) were chosen from the raw materials and the rest (raw materials) remain constant in standard quantity. Eight different experimental runs with varying factor of 20% each, in quantities of Polyvinylacatate, Titanium dioxide and Calcium carbonate were formulated and carried out. The products obtained were analyzed for weight, viscosity and specific gravity tests. The results obtained shows run number 5 to be the best as its specific gravity fall is within the standard values of 1.42 to 1.52, while its viscosity equal to the standard value of 38 poises. Therefore, improved quality without defect can be formulated when 20%increase in polyvinyl -acetate and 20% decrease, each in Titanium dioxide and Calcium carbonate besides the normal formulation used for this research. Finally, model equations were derived from the result of the factorial design experiment can be used in the production of standard texcote paint.

KEYWORDS: *Texcoat Paint, Factorial Design, Viscosity, Specific gravity, Weight*

INTRODUCTION

Paint is a fluid, with viscosity, drying time and flowing properties dictated by formulation, normally consisting of a vehicle binder, a pigment, a solvent or thinner, and a drier. It may be applied in relatively thin layers and changes to a solid with time. The change to a solid may or may not be reversible, and may occur by evaporation of the solvent, chemical reaction, or a combination of the two. In modern technology, paint is classified in three major categories because of different performance requirements. There are architectural paints, commercial finishes, and industrial coating. A fourth category, artistic media, now admits ink, cements, paste, dyes, plastic, semi solids and conventional pigmented oils as acceptable material (Gardner and Sward 1962, Cayne and Smith, 1994,)

Paint can also be regarded as a pigment – bearing liquid designed for application to a surface in a thin layer that cures to an opaque thin solid. Paint is used for many purposes. It was used for decoration long before the beginning of recorded history, and this is still a major use.

An even more important function of paint is the protection of wood and metal structures, machinery, and other artifacts that are exposed to the weather. Paint protects wood surfaces from rot and decay, and metal surfaces from oxidation and corrosion. Specialized paints are used for a wide variety of purposes, especially in industry, Skid – resistant paints are used on steps and floors. Heat reflective paints keep oil-storage tank from becoming too hot in sunny locations, and heat absorbent paints increase the efficiency of solar collector. (Parker, 1982)

The major ingredients for production of paint are pigments (including extenders), binder (or film former) and a solvent or thinner. A dispersion of the pigment in the binder constitutes the paint film, the properties of which depend to a large degree, on the nature of the binder. The nature and the quantity of the pigment are also important. The solvent or thinner is used to render the pigment or binder mixture sufficiently fluid for application as a thin film after which it is lost by evaporation and plays no part in the performance of the dry paint film. The additives employed comprise materials such as driers, anti-skinning and anti-settling agents, fungicides or bactericides and surface active agents used to assist pigment dispersion (Morgan 1990)

Some results reported in Gardner and Sward (1962) and Hess (1979) showed that physical properties of paint include opacity, glossiness, hydroscopic, weathering resistance and drying time. The mechanical properties include tensile strength, hardness, brushabilty, viscosity, dispensability and thermal capacity while chemical properties include the effect of chemical and atmospheric gases on paint.

One of the experimental models that have been successfully adapted to Chemical Engineering analysis is the 2^k factorial model. The model used consists of k factors evaluated at 2 levels. The performance of the factorial design is recorded as the response. The factors are inherent parameters of the system while the response is the measure of performance of the system with respect to the factors.

The factors used in process analysis are usually quantitative since they have numerical values. They are chosen at two levels designated by minus (-) and positive (+) signs, which are associated with the lower and the higher numerical values of the factors respectively. For a factorial model used in this work, the three factors ($CaCO_3$, Polyvinylchloride, and TiO_2) were designated x_1, x_2 and x_3. The response was designated Y and these factors are called the main factors. However, in many industrial processes factors may interact, giving rise to interaction factors. For instance, when x_1 and x_2 interact, we get interaction factor x_{12}. Similarly, we can get x_{13}, x_{23} and x_{123} .

The model resulting from the response of the factors is represented by

$$Y= b_o +b_1x_1 + b_2x_2+ b_3x_3 + b_{12}x_{12} + b_{13}x_{13} + b_{23}x_{23} + b_{123}x_{123}$$

The coefficients b_o, b_1 …….. b_{123} are called effects b_1,b_2 and b_3 are called the main effects, while the rest are the interaction effects . The full design matrix that results from the model equation is represented in Table 1

Table 1. Design matrix for the model Equation

No	X_0	X_1	X_2	X_3	X_{12}	X_{13}	X_{23}	X_{123}	Y
1	-	-	-	-	+	+	+	-	Y_1
2	+	-	-	+	-	-	+	+	Y_2
3	-	+	-	-	-	+	-	+	Y_3
4	+	+	-	+	+	-	-	-	Y_4
5	-	-	+	-	+	-	-	+	Y_5
6	+	-	+	+	-	+	-	-	Y_6
7	-	+	+	-	-	-	+	-	Y_7
8	+	+	+	+	+	+	+	+	Y_8

The sign for the interaction factors results from the multiplication of the signs of the main factors that give rise to the interaction factors. Thus, the + sign for x_{12} in row1 is obtained by multiplying the – sign of x_1 by – sign of x_2 in the same row.

Likewise, signs for x_{13}, x_{23} and x_{123} are obtained.

The significance of this research includes production of paint with improved quality and to afford Nigerians opportunities to patronize locally made paints. This research is restricted to the study of factorial design as a way of improving the quality of textcoat paint.

METHODOLOGY

Procedure for making 2 litre Texcote Paint

To 250 cm^3 volume of water in a drum, 270g polyvinyl acetate (PVA) was added and stirred continuously by mixing machine. Also, 5g Glycol, 3g Synpemic, 3g Defoarmer, were premixed and added .While mixing continues, 500g Calcium Carbonate and 100g Titanium dioxide were added together with 5g Tylose, 6g Acticide, 4g of ammonia and 500g Marble dust to the mixture. (Eagle Paint, 1995). Table 2 presents the standard formulation for the production of texcoat paint.

Table 2: Standard Formulation for the Production of 2 litre Textcoat Paint.

Raw material	Quantity (g)
Calcium Carbonate	500
Titanium dioxide	100
Polyvinyl acetate (PVA)	270
Tylose	5
Ammonia	4
Defoamer	3
Synperonic	3
Glycol	5
Calgon	2
Marble dust	500
Water	250
Acticide	6

Three materials namely $CaCO_3$, Polyvinylchloride, and TiO_2 were chosen from the raw materials and a varying factor of 20% increase or decrease in these materials were chosen and combined with fixed amounts of the remaining raw materials to obtain eight different experimental runs as shown in Table 3.

Model Data

The data used to obtain the model equations were obtained from experiment carried out in the formulation of texcoat paint production. The factors and levels are shown in Table 5, while the experimental results based on Table 4 are shown in Table 5, 6 and 7. Factors 1, 2 and 3 are masses of Calcium carbonate, polyvinyl acetate and Titanium dioxide respectively.

Table 4: The factors and their coded levels

Level of Factor	Code	Factor 1	Factor 2	Factor 3
Low level	-1	400 g	216 g	80 g
High level	+1	600 g	324 g	120g

Table 5: Data Based on 2^3 Factorial Designs (Weight)

	X_1	X_2	X_3	Y_1	Y_2	Y
1	-	-	-	5.590	5.590	5.590
2	+	-	-	6.000	6.080	6.040
3	-	+	-	5.755	5.685	5.720
4	+	+	-	6.065	6.175	6.120
5	-	-	+	5.860	5.860	5.860
6	+	-	+	6.260	6.260	6.260
7	-	+	+	5.860	5.900	5.880
8	+	+	+	6.280	6.280	6.280

Table 6: Data Based on 2^3 Factorial Designs (Viscosity)

	X_1	X_2	X_3	Y_1	Y_2	Y
1	-	-	-	34.785	35.135	34.960
2	+	-	-	40.194	40.366	40.280
3	-	+	-	39.290	39.270	39.270
4	+	+	-	41.550	41.550	41.550
5	-	-	+	38.000	38.000	38.000
6	+	-	+	43.407	43.233	43.320
7	-	+	+	39.020	39.020	39.020
8	+	+	+	43.251	43.429	43.340

Table 7: Data based on 2^3 Factorial Designs (Specific gravity)

	X_1	X_2	X_3	Y_1	Y_2	Y
1	-	-	-	1.370	1.390	1.380
2	+	-	-	1.600	1.580	1.590
3	-	+	-	1.550	1.550	1.550
4	+	+	-	1.660	1.620	1.640
5	-	-	+	1.500	1.500	1.500
6	+	-	+	1.730	1.690	1.710
7	-	+	+	1.530	1.550	1.540
8	+	+	+	1.750	1.750	1.750

Determination of Viscosity

Using the Rotothiner, a given amount of paint was placed in a 250cm^3 tin on the turn-able and the stirrer lowered at room temperature. The torque transmitted through the liquid exerts a twist on the turn-able, the base of which is marked off in

Table 3: Raw materials used for experimental runs.

Material Used	*Run 1*	*Run 2*	*Run 3*	*Run 4*	*Run 5*	*Run 6*	*Run 7*	*Run 8*
$CaCO_3$	400	600	400	600	400	600	400	600
PVA	216	216	324	324	216	216	324	324
TiO_2	80	80	80	80	120	120	120	120
Tylose	5	5	5	5	5	5	5	5
NH_3	4	4	4	4	4	4	4	4
Defoarmer	3	3	3	3	3	3	3	3
Synperonic	3	3	3	3	3	3	3	3
Glycol	5	5	5	5	5	5	5	5
Calgon	2	2	2	2	2	2	2	2
Marble dust	500	500	500	500	500	500	500	500
Water	250	250	250	250	250	250	250	250
Acticide	6	6	6	6	6	6	6	6

Determination of Specific gravity

For rough determination, a hydrometer was used. It is essential to note the temperature and to use measurements recommended by the manufacturer of the specific gravity bottle or the Westphal balance (Morgan, 1990).

RESULTS AND DISCUSSION

RESULTS

The analysis of variance for weight, viscosity and specific gravity is shown in Table 8, 9 and 10 respectively.

Table 8: Analysis of Weight Variance for Replicated 2^3 factorial

Regression coefficient	*Estimated Effect*	*Confidence interval*	*T- values*
b_0	5.975	0.0269	510.68
b_1	0.200	0.0269	17.09
b_2	0.025	0.0269	2.137
b_3	0.095	0.0269	8.120
b_{12}	0.000	0.0269	0.000
b_{13}	0.000	0.0269	0.000
b_{23}	-0.015	0.0269	1.280
b_{123}	0.000	0.0269	0.000

Summary of important parameters obtained from 2^3 Factori[al] Designs of weight are:

G- Calculated = 0.345

G- Statistical Table = 0.768

G- TEST

From Table 9, it is possible to carry out regression analys[is] since

G – Statistic > G- calculated.

i.e. 0.768 > 0.345

T TEST

T – Statistical Table. = 2.306

Coefficients b_2, b_{12}, b_{13}, b_{23} and b_{123} for variables X_2, X_{12}, X_{13}, X_{23}, and X_{123} are insignificant since T-calculated < T Tab[le]

Therefore the fitted model equation for weight becomes:

$Y = 5.975 + 0.200x_1 + 0.095x_3$ ----------------( )

F- TEST

F – Calculated = 0

F- Statistical Table = 4.46

Since the F-cal. < F- table, the model equation is adequ[ate]

Thus, the model equation describing the weight of tex[coat] paint is $Y = 5.975 + 0.200x_1 + 0.095x_3$

Table 9: Analysis of Viscosity Variance for Replicated 2^3 Factorial

Regression coefficient	*Estimated Effect*	*Confidence interval*	*T-values*
b_0	39.968	0.0669	1378.19
b_1	2.155	0.0669	74.31
b_2	0.828	0.0669	28.534
b_3	0.953	0.0669	32.845
b_{12}	-0.505	0.0669	17.414
b_{13}	0.255	0.0669	8.793
b_{23}	-0.568	0.0669	19.569
b_{123}	0.255	0.0669	8.793

Similarly, parameters obtained from the 2^3 Factorial Designs of viscosity are:

G- Calculated = 0.568

G- Statistical Table = 0.768

G- TEST

From Table 10, it is possible to carry out regression analysis, since

G – Statistic > G- calculated.

i.e. 0.768 > 0.568

T TEST

T – Statistical Table. = 2.306

Since T-calculated >T Table, all the coefficients and the variables are significant. Therefore the fitted model equation for viscosity becomes:

$Y = 39.968 + 2.155x_1 + 0.828x_2 + 0.953x_3 - 0.505x_1x_2 + 0.255x_1x_3 - 0.568x_2x_3 + 0.255x_1x_2x_3$.

F- TEST

F – Calculated = 0

F- Statistical Table = 4.46

Since the F-cal. < F- table, the model equation is adequate. Thus, the model equation to describe the viscosity of texcote paint is

$$Y = 39.968 + 2.155x_1 + 0.828x_2 + 0.952x_3 - 0.505x_1x_2 + 0.255x_1x_3 - 0.568x_2x_3 + 0.255x_1x_2x_3 \quad (2)$$

Table 10: Analysis of Specific Gravity Variance for Replicated 2^3 Factorial

Regression coefficient	*Estimated Effect*	*Confidence interval*	*T-values*
b_0	1.583	0.0166	381.45
b_1	0.090	0.0166	21.687
b_2	0.038	0.0166	9.036
b_3	0.043	0.0166	10.241
b_{12}	-0.015	0.0166	3.614
b_{13}	0.015	0.0166	3.614
b_{23}	-0.018	0.0166	4.217
b_{123}	0.015	0.0166	3.614

In the same manner, parameters obtained from the 2^3 Factorial Designs of specific gravity are:

G- Calculated = 0.364

G- Statistical Table = 0.768

G- TEST

From Table 11 it is possible to carry out regression analysis, since

G – Statistic > G- calculated.

i.e. 0.768 > 0.364

T TEST

T – Statistical Table. = 2.306

Since T-calculated >T Table, all the coefficients and the variables are significant. Therefore the fitted model equation for specific gravity becomes:

$Y = 1.583 + 0.090x_1 + 0.038x_2 + 0.043x_3 - 0.015x_1x_2 + 0.015x_1x_3 - 0.078x_2x_3 + 0.015x_1x_2x_3$.

F- TEST

F – Calculated = 0

F- Statistical Table = 4.46

Since the F-cal. < F- table, the model equation is adequate. Thus, the model equation to describe the specific gravity of texcote paint is

$$Y = 1.583 + 0.090x_1 + 0.038x_2 + 0.043x_3 - 0.015x_1x_2 + 0.015x_1x_3 - 0.078x_2x_3 + 0.015x_1x_2x_3 \quad (3)$$

DISCUSSION

From Table 5, the weight of the experimental runs varies with their combinations. The standard weight of a textcoat paint of 2 litres is between 5.50 – 6.00 Kg. (Eagle Paint, 1995).

Experimental runs 2,4,6,8 are with weights greater than 6.0 kg. This means, the bulking agent is too much and the samples may be chalking in nature. Experimental runs 1, 3, 5 and 7 are within the standard range of weight for textcoat paint. Thus, 20% reduction in the amount of $CaCO_3$ has positive influence on weight of the textcoat paint.

But reduction in amount of $CaCO_3$ doesn't necessary gives quality textcoat paint.

Some results reported in Eagle paint (1995) showed the standard viscosity of textcote paint to be 38 poises. From Table 6, Experimental run 1 is substandard, because its viscosity is lesser than the standardized value of 38 poises. It simply means that the thinner is too much. Experimental runs 2, 3,4,6,7 and 8 needs to be standardized by adding more suitable solvent, because their viscosities are more than 38 poises. The thickness of these paints will be too much and can cause brush drag. Only experimental run 5 meet up with the standard viscosity value of textcoat paint.

The standard specific gravity of textcote paint is between 1.42 – 1.52. From Table 7, experimental run1 is having low specific gravity and the other runs except experimental run 5 had higher values of specific gravity when compared to the standardized range of 1.42 – 1.52. From the analysis, experimental run 5 with 20% increase in TiO_2 and 20% decrease each in polyvinylchloride and $CaCO_3$ retained the quality of a good paint. I.e. 400g $CaCO_3$, 216g polyvinylchloride and 120g TiO_2 gives a product having its weight, specific gravity and viscosity within the range specified for the texcoat paint from Eagle paint, Nigeria.

Considering equation1, there is a direct relationship between x_1 and x_3 with the weight of textcote paint. There are no interactions between any of the components. I.e. coefficients b_2, b_{12}, b_{13}, b_{23} and b_{123} were less than T- Table value. Thus they are considered insignificant on the weight of texcoat paint. From equation 2, it is observed that there is direct relationship between x_1, x_2, and x_3, and the viscosity of the text coat paint. This means that the higher the concentrations of T_1O_2, PVA and $CaCO_3$, the more viscous the paint. Since $b_1 > b_3 > b_2$, the concentration of x_1 ($CaCO_3$) have the greatest significance on the viscosity properties of textcoat paint. There are 3 main effect factors, 3 two interacting factors and a three factors interaction. There is an inverse relationship between viscosity of texcote paint and the interaction of x_1 and x_2 or x_2 and x_3. While there is a direct relationship between viscosity and the interaction of x_1 and x_3 or x_1, x_2 and x_3.

There are 3 main effects, 3 two factors interaction and a three factors interaction in equation 3. Therefore, this model can be regarded as a specific gravity cubic model equation. There is an inverse relationship between the interaction of x_1x_2 and x_2x_3 with the specific gravity of textcoat paint .There is also a direct relationship between specific gravity of texcote paint and the interaction of x_1 and x_3 or x_1, x_2 and x_3.

Since $b_1 > b_3 > b_2$, concentration of x_1 produces texcote paint with highest specific gravity.

For viscosity:

$$Y = 39.968 + 2.155x_1 + 0.828x_2 + 0.952x_3 - 0.505x_1x_2 + 0.255x_1x_3 - 0.568x_2x_3 + 0.255x_1x_2x_3$$

For specific gravity:

$$Y = 1.583 + 0.090x_1 + 0.038x_2 + 0.043x_3 - 0.015x_1x_2 + 0.015x_1x_3 - 0.078x_2x_3 + 0.015x_1x_2x_3$$

For weight:

$$Y = 5.975 + 0.200x_1 + 0.095x_3$$

CONCLUSIONS

From the analysis of the experimental runs products, there is direct relationship with the factor of production chosen to be varied. Thus, 400g $CaCO_3$, 216g polyvinylchloride and 120g TiO_2 gives a product having its weight, specific gravity and viscosity within the range specified for the texcoat paint. That is, 20% increase in quantity of Titanium dioxide and 20% decrease, each in quantities of polyvinyl acetate and Calcium carbonate gives an improved quality of paint. From the viscosity model equation $b_1 > b_3 > b_2$. So, one can conclude that component 1 produces paint with highest the highest viscosity. Moreover, since b_{13} and b_{123} are positive; blending components 1 and 3 or components 1, 2 and 3 produces higher viscosity values that would be expected just by averaging the viscosity of the pure blends.

Considering the weight model equation, blending components 1 and3 or components 1, 2, and 3 have no effect on the weight of the paint because b_{13} and b_{123} are all zero. From the specific gravity model equation, b_{23} is negative. Therefore, blending components 2 and 3 have antagonistic effect on the specific gravity of the paint.

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