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Developing A New Empirical-Computational Method, for Accurate Acid-Base Quantitative Analysis

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ABSTRACT

The mole ratio of an acid base reaction is one of the important values to state the stoichiometric relationship between acids and bases. However, solving acid-base problems based on stoichiometry is still challenging for new chemists.This issue renders the use of a model for predicting the volume of the acid used an exciting endeavour in academia. This work was to study the individual and interactive effects of the titration parameters such as acid concentration, base concentration and the number of the indicator drops on the volume of acid used in the titration process, using methyl orange as an indicator.We also aimed to study the central composite design (CCD) model of response surface methodology (RSM) for experimental design and modelling of the process. The experimental data were analysed using analysis of variance (ANOVA) and fitted to a second-order polynomial equation using multiple regression analysis. The regression analysis showed a good fit of the experimental data to the second-order polynomial model with a coefficient of determination (R2) value of 0.9751 and model F-value of 43.37. The response surface and contour plots were generated from RSM tool for the interactive effects of the studied parameters on the volume of acid used. The developed model was further validated using existing acid-base titration problems from the Senior Secondary Certificate Examination (SSCE) past questions over 30 years. All observations indicated that the developed model was only valid for a monobasic acid.

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1. Introduction

The assessment of students on the quantitative analysis in Chemistry and Chemical Engineering, especially for reactions that involve acids and base is often and widely encountered at both graduate and undergraduate levels. Details of such analysis can be found in Literature.[1]–[5]. Over the years, the concept of mole ratio has always been adopted at all levels for subsequent titrimetric calculations [6]–[8].This approach is acceptable, especially in terms of accuracy but has some strict limitations. For instance, acid-base reactions must be well written and balanced stoichiometrically. However, this is an aspect which students find difficult to understand, especially when unusual acids and bases with high acidity and basicity is involved. More so, the acid-base indicator dose, could affect the endpoint during titration, which is sometimes missing in the mole concept application. However, information about the relationship between the concentration of acids, bases and drops of indicator for the calculation of the average titre is still limited. Therefore, the acid-base titration process was modelled using response surface methodology (RSM). The modelling considered the concentration of acid, base and drops of indicator for the prediction of the volume of the required acid.

The Response Surface Methodology (RSM) is an empirical modelling and optimizing tool, used to find out the relationship between a set of experimental or process parameters and the observed results [9]. To correctly use the RSM, the experiments have to be statistically designed followed by experiments, estimates of the coefficients in the mathematical model and predicting the response and lastly checking the adequacy of the model[10]. Some of the efficient designs used in RSM are the Box–Behnken design, the central composite and Doehelrt designs[11]. RSM has many advantages; it reduces the number of planned experiments and suitable to determine optimum parameters, particularly when it comes to the interactions of each variable[12].It further can define the influence of independent variables on the responses either by each single variable or via combination in the process[13].

The RSM is an essential optimization tool that has been widely applied in a wide range of fields such as transesterification[14], [15], solvent extraction,[16], [17]adsorption, [18], [19] Fenton process,[20] drying operations,carrageenan production, [22] synthesis andprocessing [23]–[25]etc.To the best of our knowledge, RSM is considered suitable for acid-base titrations,which will be discussed here. This study, therefore, focused on the determination of optimum conditins of the acid-base titration conditions, developmentof a statistical, computational model for the prediction of the titre values, validation of the developed model and finally, the determination of the strength and limitations of the developed model.

2. Materials and Methods

2.1 Materials

The reagents and apparatus used are Hydrochloric acids, Potassium hydroxide, methyl orange, distilled and de-ionized water, and burette. All the reagents were of analytical grade, purchased from Sigma Aldrich.

2.2 Acid-Base Titrations

The acid-base titrations were performed out as designed by the RSM tool (Table 2). Each experimental design was performed in triplicates for accuracy and precision using 25 cm3 pipette size, and the average volume of the acid used was calculated in each case.

2.3 Designing of the Experiment

The acid-base titrations were carried out as deigned by the RSM tool shown in Table 2. The studied variables studied were the concentration of the acid (CA) concentration of the base (CB) and drops of indicator (ID). All variables and their respective range were in Table 1 based on the preliminary studies of this acid base titration method. A five-level-three-factor central composite design (CCD) was used. This required 20 experimental runs (calculated based on Equation (1) with the following distributions; 8 factorial runs, 6 axial runs and 6 replicates runs at the centre.

$$N=2^{n^*}+2n^*+N_c \quad \text{-------} \ (1)$$

Where N is the total experimental runs, n* is the number of variables and Nc is the centre point replication.

The response to the titration experiment was the average volume of the acid used (VA) or titre value (Y). The response was used to develop an empirical/statistical model of the form of (Equation 2) that correlated the response to the three titration variables using a second-degree polynomial.Coded values were obtained directly from the optimization tool used to represent the actual values.

$$Y = b_o + \sum_{i=1}^{n} b_i X_i + \sum_{i=1}^{n} b_{ii} X_{ii} + \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} b_{ij} X_i X_j$$

------- (2)

Where Y is the predicted response, b_o is a constant coefficient, b_i is a linear coefficient, b_{ii} is the quadratic equation, b_{ij} is an interaction coefficient, and X_i and X_j are the coded values of the titration variables.

3. Results and Discussions

Table 2 (standard experimentation matrix) showed the run order, the experimental design and the observed response (titre value) for the three variables and 20 experimental runs generated. Columns 2 to 4 represented levels of the variable levels coded in the dimensionless coordinate, while columns 5 to 7 represented the actual dimensional variable levels. Column 8 similarly showed the experimental values obtained by the current response, while column 9 shows the predicted response.

3.1 Statistical Analysis

Design-Expert software (MINITAB 16.1) was used for RSM regression analysis. The statistical analysis of variance (ANOVA) was used to analyse the model, the analyses included linear, quadratic and interaction coefficient, with F-test to obtain the empirical correlation between input and output parameters. To examine the goodness-of-fit, of the model, for each term of the model was tested statistically to confirm the significance of F - values with $p \leq 0.05$. The influence of the term (titration parameter) was significant only when $p < 0.05$ (Box et al., 2005). The values R2 (Coefficient of determination), adjusted R2, and predicted R2, lack of fit and adequate precision of models were obtained to check the strength of the suggested algebraic model. The response surface plot and contour plot were also drawn to determine the input-output relationships.

Table 1:Experimental variables and their coded levels for central composite design

Variables	Variables	Units	CodedVariables Level		
			-1	0	1
Concentration of Acid	CA	Mole/L	0	1	1
Concentration of Base	CB	Mole/L	0	1	1
Drops of indicator	ID	---	1	2	3

Table 2: Experimental design matrix for the Acid Base Titration Process.

Run	Coded Factor			Actual Factor			% Conversion	
	CA	CB	ID	CA (mol/L)	CB	ID	Observed response	Predicted response
1	-1	-1	1	0.1	0.1	3	22.75	28.96
2	1	0	0	0.9	0.5	2	12.15	11.62
3	1	-1	1	0.9	0.1	3	2.50	9.49
4	0	1	0	0.5	0.9	2	41.45	68.02
5	0	0	0	0.5	0.5	2	22.50	22.39
6	0	0	0	0.5	0.5	2	22.50	22.39
7	0	-1	0	0.5	0.1	2	4.80	21.53
8	0	0	0	0.5	0.5	2	22.50	22.39
9	-1	0	0	0.1	0.5	2	113.00	113.87
10	1	-1	-1	0.9	0.1	1	2.60	9.08
11	1	1	1	0.9	0.9	3	22.75	16.11
12	-1	1	1	0.1	0.9	3	207.20	200.60
13	0	0	1	0.5	0.5	3	22.60	22.60
14	-1	1	-1	0.1	0.9	1	208.60	201.50
15	0	0	0	0.5	0.5	2	22.50	22.39
16	0	0	0	0.5	0.5	2	22.50	22.39
17	-1	-1	-1	0.1	0.1	1	22.50	29.05
18	0	0	0	0.5	0.5	2	22.50	22.39
19	0	0	-1	0.5	0.5	1	22.50	22.84
20	1	1	-1	0.9	0.9	1	22.80	16.50

3.2 Development of the Regression Model Equation

The observed volume of the acid used for the 20 experimental runs was presented in Table 2. The data obtained was used to determine the coefficients of the polynomial equation (Equation 2). These estimated coefficients for both the uncoded and actual values are shown in Table 3 along with the coefficient of determination R2, adjusted R2, and predicted R2.

$$V_A = 31.598 - 251.694C_A + 236.556C_B - 1.335I_D + 252.202C_A^2 + 5.327C_B^2 + 0.327I_D^2 - 257.891C_AC_B + 0.313C_AI_D - 0.5C_BI_D \text{ ------- } (3)$$

Equation 3, showed that the base's concentration had a positive effect on the volume of acid used. A positive value represented a progressive effect while a negative value represented an antagonistic effect. Both coefficient of CA and CB were large and opposite which was expected as they neutralize each other.

3.3 Analysis of Variance (ANOVA)

The estimated regression coefficient and the analysis of variance (ANOVA) are shown in Table 3 and Table 4, respectively. Table 3 showed that the linear term CA and CB had significance influence on the model, where only one quadratic term CA2 and one interaction term CACB had a significance influence on the model because the probability value (p-value) of each term is less than 0.05. The other terms have no significant effect on the volume of acid used. The coefficient of determination (R2) that fitted the model was 0.9751 which indicated a good fit between the experimental data points and the predicted values. This R2 value indicated that 97.51% of the variations used to determine the volume of the acid were explained by the model, and only 2.49 % of the total variations were not explained by the model. The R2 value was close to 1 which confirmed the adequacy of the model to predict the volume of acid used. A high value of the adjusted determination coefficient (R2Adj = 0.9526) was estimated which indicated that 95.26% of the total variation on the titration data can be described by the developed model. The accepted adjusted R2 and predicted R2 values should be within 0.2 of each other. In this study, the predicted R2 of 0.8065 was in reasonable agreement with the adjusted R2 of 0.9526 due to the acceptable difference (0.1461).

Table 3 Coefficient of the Regression Model

Factors	Coefficients	
	Uncoded (Actual)	Coded
Constant	31.598	31.17
CA	-251.69	57.83
CB	236.556	57.83
ID	-1.335	33.17
CA2	252.202	49.78
CB2	5.327	49.78
ID2	0.327	7.964
CACB	-257.89	29.18
CAID	0.313	11.67
CBID	-0.5	11.67
R2	97.51%	
Adjusted R2	95.26%	
Predicted R2	80.65%	

Table 4 Analysis of Variance (ANOVA)

Source	DF	Seq Sum ofSquares	Adj Sum of Squares	Adj Mean Sum of Squares	F-value	P-value
Regression	9	68,240.00	68,240.00	7,582.20	43.47	Not Applicable
Linear	3	46,185.80	5,130.30	1,710.10	9.80	0.00
CA	1	26,137.70	3,303.70	3,303.70	18.94	0.00
CB	1	20,048.00	2,918.30	2,918.30	16.73	0.00
Id	1	0.10	0.30	0.30	-	0.97
Square	3	8,433.00	8,433.00	2,811.00	16.12	Not Applicable
CA2	1	8,429.60	4,477.80	4,477.80	25.67	
CB2	1	3.00	2.00	2.00	0.01	0.92
ID2	1	0.30	0.30	0.30	-	0.97
Interaction	3	13,621.20	13,621.20	4,540.40	26.03	Not Applicable
CACB	1	13,620.80	13,620.80	13,620.80	78.09	Not Applicable
CAID	1	0.10	0.10	0.10	-	0.98
CBID	1	0.30	0.30	0.30	-	0.97
Residual error	10	1,744.30	1,744.30	174.40		
Lack of Fit	5	1,744.30	1,744.30	348.90		
Pure error	5	-	-	-		
Total	19	69,984.30				

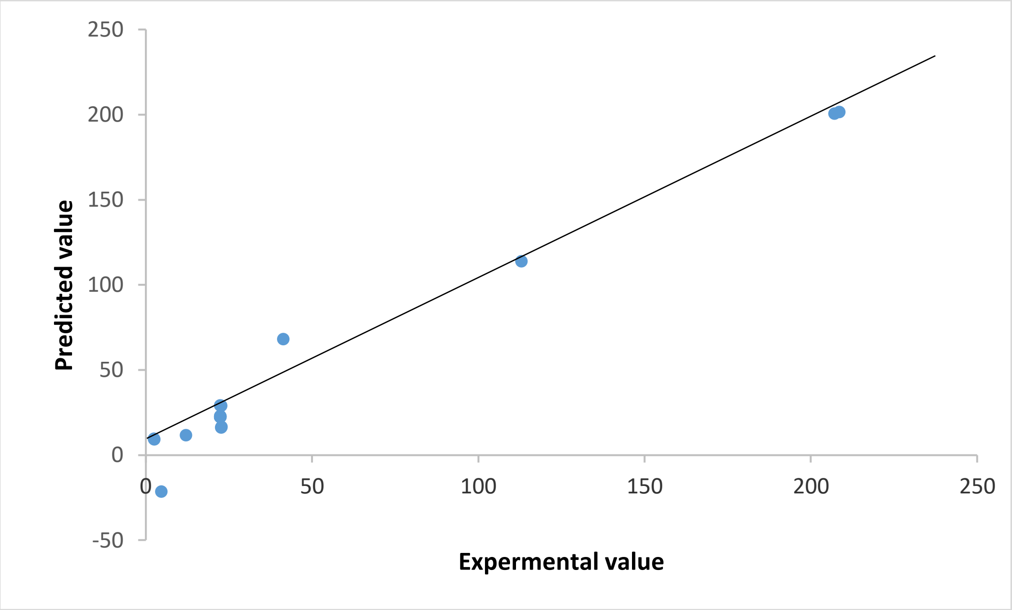

Fig. 1. The Experimental Volume of the acid versus the predicted values by the model

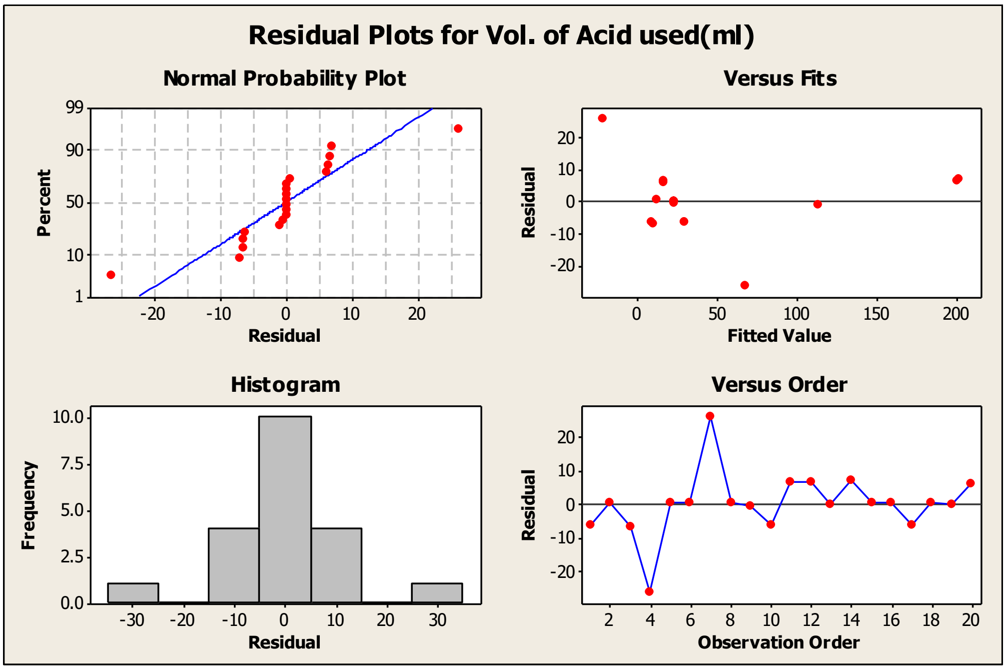

Fig. 2. Residual plots of the volume of the acid used

Figure 1 showed a plot of the predicted volume of the acid used by the developed model against the experimental values. The points are around the line drawn on Figure 1. This shows the model captured the correlation between the titration process parameters and the volume of the acid. Figure 2 showed the normal probability plot of the residual of the titration process according to the volume of acid used. The residual showed a semi straight line were the errors were distributed normally. On the other hand, the residual plot versus fitted values in Figure 2 showed that the residual was independently distributed with zero mean and a constant variance. These observations could suggest that the model suggested are adequate and satisfied.

3.4 Analysis of the Responded Surface

The response surfaces in three dimensions were plotted to scrutinize the interaction among the variables and to determine the optimum condition of each of the factor for lesser volume of the acid used. The effect of acid concentration and base concentration on the volume of the acid at constant indicator drop of 2 ml is presented in Figure 3. As the acid concentration and base concentration was increased, the volume of the acid used decreased. The minimum volume of the acid used was obtained at a base concentration of 0.8125M. Therefore, an acid concentration of 0.96875M and a base concenrtation of 0.8125M could be optimum for a minum vlume of the acid. There was a significant negative interaction between acid concentration and base concentration. Figure 4 showed the interactive effect of the acid concentration and indicator drops on the acid’s volume a constant base concentration of 0.5M. The volume of acid was decreased as the acid concentration increased in acid concentration compared to that of indicator drops. Figure 5 showed the interactive effect of base concentration and indicator drops on the volume of the acid at a constant acid concentration of 0.5M.

3.5 Analysis of the Contour Lines

Figure 6 showed the contour plots of the acid’s volume as a function of the base and the acid concentration. High base concentration and low acid concentration (between 0.1 and 0.25M) would increase the volume of the acid. Precisely, a volume of acid above 200 mL, 150-200 mL, 100-150 mL, 50-100 mL, 0-50 mL were obtainable at base concentrations of 0.67, 0.44, 0.2, 0.1M respectively at a constant indicator’s drop of 2 mL. The base concentration and acid concentration showed a suppressive effect on each other.

Figure 7 showed the contour plots of the acid’s volume as a function of the indicator drops and the acid concentration. Increase in indicator drops and the acid concentration, at a constant base concentration at 0.5M has decreased the volume of acid. Whereas, a decrease in the indicator drops with the corresponding decrease in acid concentration has increased the volume of the acid. However, the volume of the acid did not change when the acid concentration increased at a constant value of the indicator's drop. This could indicate that the interactive effect of indicator drops and acid concentration does not have a significant effect on the volume of the acid used.

A comparative effect of the variables (indicator drops and base concentration) was showed in Figure 8 where low base concentration (less than 0.1M), and high indicator' drops, caused a negative volume of the acid. Increase in indicator's drop at a base concentration between 0.3-0.9M and a constant acid concentration of 0.5M, increased in the volume of acid, increased the base concentration at a constant indicator's drop, did not affect the volume of acid. This indicated that the interactive effect of the indicator drops and base concentration had non- significantly influenced the acid 'volume.

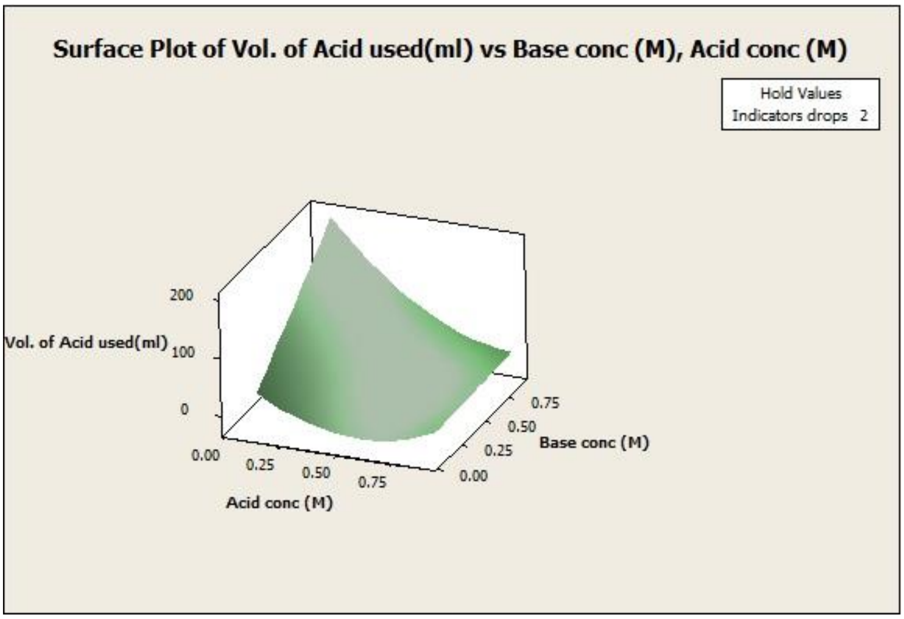

Fig. 3. A plot of response surface plot of the interactive effect of acid concentration and base concentration on the acid's volume at constant indicator drops.

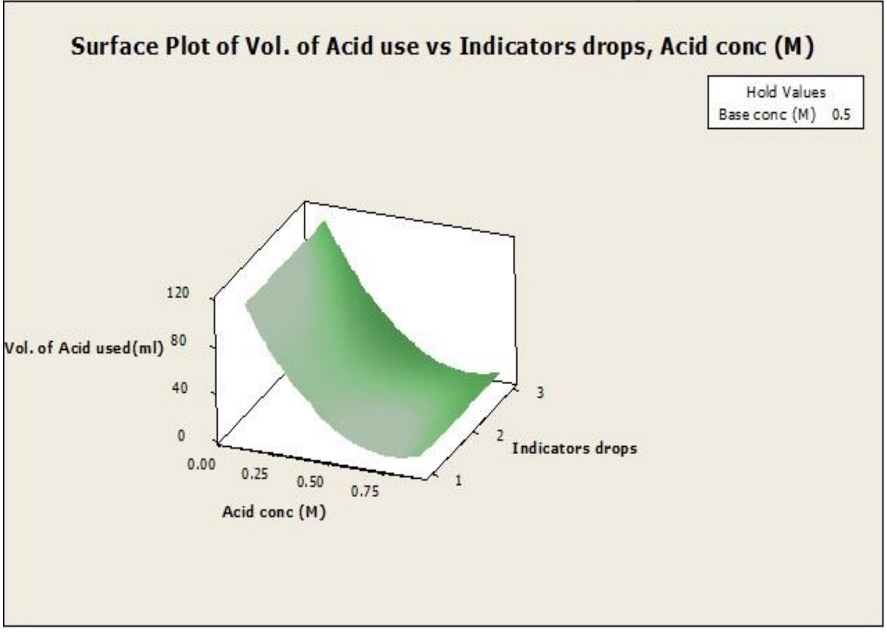

Fig. 4. : A plot of response surface plot of the interactive effect of the acid concentration and indicator drops on the acid's volume, at constant base concentration of 0.5M

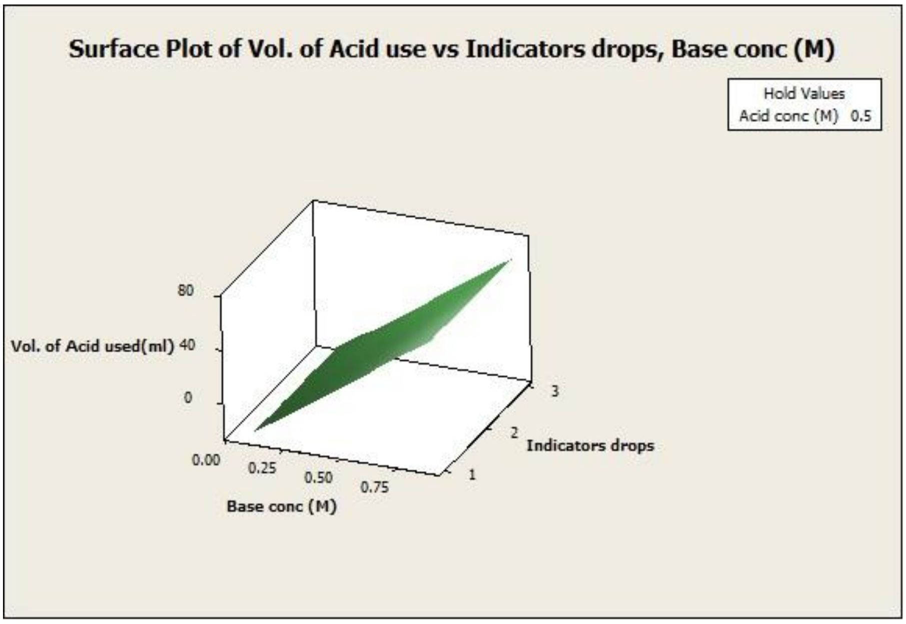

Fig. 5. A plot of response surface plot of the interactive effect of base concentration and indicator drops on the acid's volume, at constant acid concentration of 0.5M.

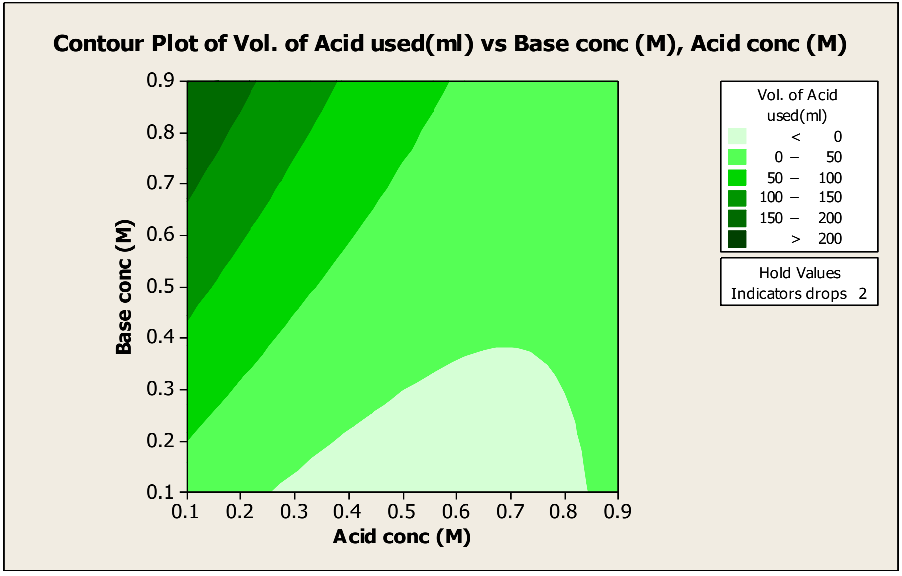

Fig. 6. A contour plot of the acid's volume of acid against base's concentration and acid's concentration at a constant Indicator's drop of 2mL

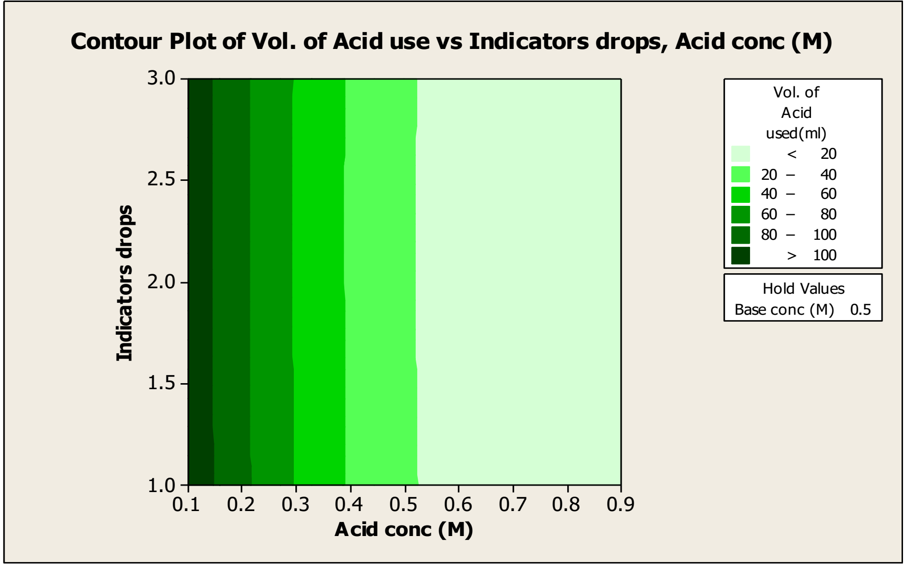

Fig. 7. A Contour plot of acid's volume against indicator's drops and acid's concentration,at a constant base concentration at 0.5M

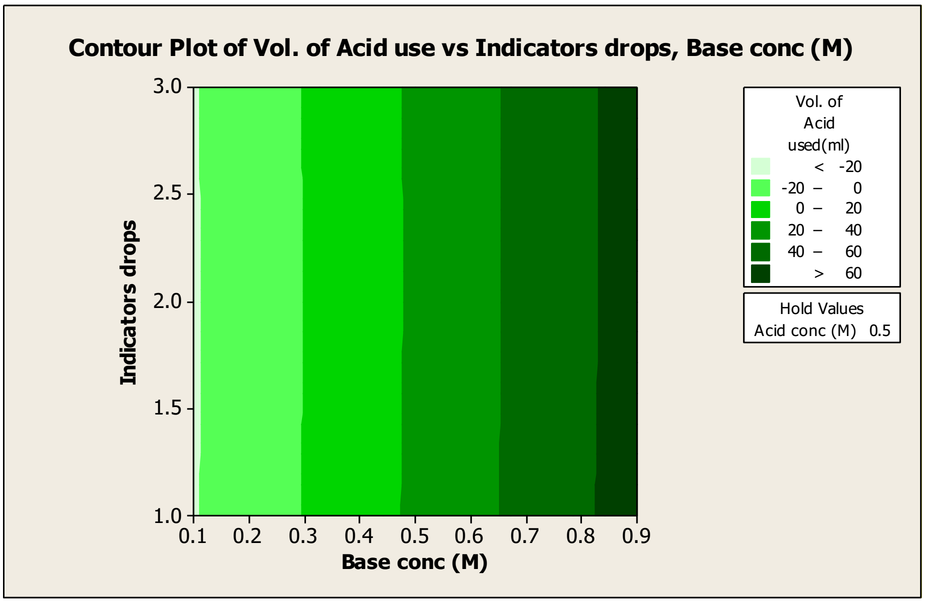

Fig. 8. A Contour plot of acid's volume against indicator drops and base concentration

4. Validation of the Model

The model was validated by comparing the experimental volume of the acid with that of the model. The experimental values were all agreed with the predicted value primarily in the experimental runs 2, 5, 6, 8-9, 12-16, and 18-20.

The model was further validated by testing the model 1(with both significant and non-significant terms) and model 2 (with only significant terms) with acid-base titration practical problems from chemistry Senior Secondary Certificate Examination (SSCE) past questions from 1988 till 2017 as shown in Table 5. The volume of the acid in model1 had a minimum error of 0.744 mL and maximum error of 6.62mL compared with the experimental value from the past question. The volume of acid from model 2 had a minimum error of 0.054 mL and maximum error of 7.99 mL compared with the experimental value from the past question.

The sensitivity of the data was analysed, where any parameter out of the significancy limit of p values (≤0.05) was removed from the actual model. Both models (original model and the shortened model) were validated.Minor differences were found between both models.This was as a result of just few parammeters discovered as non- significatants such a drops of indicators and some interactive terms.

Table 6 showed instances where the developed model seems to demonstrate high predictive strength. This instance included using acid and base of almost equal concentration with 2 or 3 drops ofindicator. Acid-base titration between HCl and Na2CO3, KOH was strongly followed by the developed models. A titration between HNO3 and Na2CO3, and the redox titration between H2CrO4 and KMnO4 responded well to the predictions of the models. Table 7 similarly presented the predictions of both the original model and shortened model to the titration cases with large deviations from the original predictions.The titrations for such involves dibasic acid.The shortened model still predicted closely to the original model as early observed.

Table 5: Table showing the model 1 and model 2 volume of acid used against experimental volume of acid used.

Model 1: VA = 31.598 – 251.694CA + 236.556CB – 1.335ID + 252.202CA2 + 5.327CB2 + 0.327ID2 – 257.891CACB + 0.313CAID – 0.5CBID

Model 2: VA = 31.598 – 251.694CA + 236.556CB + 252.202CA2 – 257.891CACB

Year	Acid(A)	Base(B)	CA(M)	CB(M)	Indicator	Indicator drops	ᵃExp VA used (ml)	Model VA used (ml)	Model 2 VA Used (ml)
1988	HCl	Na2CO3	0.1000	0.0125	methyl orange	2	6.20	10.27	11.59
1990	H2SO4	KOH	0.1040	0.2000	methyl orange	2	24.10	48.81	50.10
1992	H2X	NaOH	0.0510	0.1000	methyl orange	3	24.40	40.65	41.76
1994	H2SO4	Na2CO3	0.0500	0.0450	methyl orange	3	22.57	28.64	29.71
1995	H2C2O4	NaOH	0.0610	0.1000	Phenolphthalein	2	20.63	37.90	39.27

Table 5: Table showing the model 1 and model 2 volume of acid used against experimental volume of acid used.

Model 1: $VA = 31.598 - 251.694CA + 236.556CB - 1.335ID + 252.202CA2 + 5.327CB2 + 0.327ID2 - 257.891CACB + 0.313CAID - 0.5CBID$

Model 2: $VA = 31.598 - 251.694CA + 236.556CB + 252.202CA2 - 257.891CACB$

Year	Acid(A)	Base(B)	CA(M)	CB(M)	Indicator	Indicator drops	[a]Exp VA used (ml)	Model VA used (ml)	Model 2 VA Used (ml)
1996	H2SO4	KOH	0.0680	0.1000	methyl orange	2	18.26	36.18	37.55
1997	HCl	Na2CO3	0.0500	0.0250	methyl orange	2	23.10	23.88	25.24
1998	KHSO4	NaOH	0.1030	0.0990	methyl orange	2	24.07	27.79	29.14
1999	H2X	NaOH	0.1150	0.2150	methyl orange	3	23.27	49.44	50.47
2000	HNO3	K2CO3	0.1020	0.0500	methyl orange	3	24.40	18.03	19.06
2001	HCl	KHCO3	0.1000	0.0990	methyl orange	2	24.87	28.47	29.82
2002	H2SO4	NaOH	0.1250	0.2250	methyl orange	2	22.50	48.81	50.05
2003	HCl	X2CO3	0.2000	0.0780	methyl orange	2	19.45	4.49	5.78
2004	HCl	KOH	0.1400	0.1000	methyl orange	2	18.53	20.03	21.35
2005	H2SO4	Na2CO3	0.0500	0.0420	methyl orange	2	21.05	27.67	29.04
2006	HNO3	Na2CO3	0.1000	0.0457	methyl orange	3	22.85	17.56	18.58
2007	HCl	Na2CO3	0.0569	0.0270	methyl orange	3	24.03	23.04	24.08
2008	H2X	NaOH	0.0500	0.1000	Phenolphthalein	2	23.70	40.63	42.01
2009	HCl	X2CO3.10H2O	0.0950	0.0819	methyl orange	3	43.10	26.27	27.33
2010	NaHSO4	NaOH	0.1000	0.0916	methyl orange	2	22.90	26.91	28.26
2011	Acid	KOH	0.1000	0.1220	methyl orange	2	25.20	33.32	34.66
2012	H2Y	NaOH	0.0520	0.0975	methyl orange	2	23.33	39.57	40.95
2013	H2SO4	XOH	0.0500	0.0510	methyl orange	2	12.75	29.68	31.05
2014	HCl	Na2CO3	0.1900	0.0920	methyl orange	3	24.10	9.16	10.14
2015	HNO3	Na2CO3	0.1000	0.0301	methyl orange	3	15.03	14.29	15.29
2016	H2C2O4	KMnO4	0.0500	0.0200	methyl orange	3	24.70	23.07	24.12
2017	HCl	Na2CO3.10H2O	0.2000	0.1000	methyl orange	3	24.40	8.87	9.85

a = chemistry Senior Secondary Certificate Examination (SSCE) past questions from 1988 till 2017

Table 6: Model Response and experimental values

Model 1: $VA = 31.598 - 251.694CA + 236.556CB - 1.335ID + 252.202CA2 + 5.327CB2 + 0.327ID2 - 257.891CACB + 0.313CAID - 0.5CBID$

Model 2:VA = 31.598 – 251.694CA + 236.556CB + 252.202CA2 – 257.891CACB

Year	Acid(A)	Base(B)	CA(M)	CB(M)	Indicator	Indicator drops	Exp VA used(ml)	Model VA used(ml)	Model 2 VA used(ml)
1997	HCl	Na2CO3	0.0500	0.0250	methyl orange	2	23.10	23.88	25.24
2004	HCl	KOH	0.1400	0.1000	methyl orange	2	18.53	20.03	21.35
2007	HCl	Na2CO3	0.0569	0.0270	methyl orange	3	24.03	23.04	24.08
2015	HNO3	Na2CO3	0.1000	0.0301	methyl orange	3	15.03	14.29	15.29
2016	H2C2O4	KMnO4	0.0500	0.0200	methyl orange	3	24.70	23.07	24.12

Table 7: Model response values not approximately equivalent to experimental values

Year	Acid(A)	Base(B)	CA(M)	CB(M)	Indicator	Indicator drops	Exp VA Used (ml)	Model VA used (ml)	Model 2 VA used (ml)
1988	HCl	Na2CO3	1.00E-01	1.25E-02	methyl orange	2	6.20	10.27	11.59
1990	H2SO4	KOH	1.04E-01	2.00E-01	methyl orange	2	24.10	48.81	50.10
1992	H2X	NaOH	5.10E-02	1.00E-01	methyl orange	3	24.40	40.65	41.76
1994	H2SO4	Na2CO3	5.00E-02	4.50E-02	methyl orange	3	22.57	28.64	29.71
1995	H2C2O4	NaOH	6.10E-02	1.00E-01	Phenolphthalein	2	20.63	37.90	39.27
1996	H2SO4	KOH	6.80E-02	1.00E-01	methyl orange	2	18.26	36.18	37.55
1998	KHSO4	NaOH	1.03E-01	9.90E-02	methyl orange	2	24.07	27.79	29.14
1999	H2X	NaOH	1.15E-01	2.15E-01	methyl orange	3	23.27	49.44	50.47
2000	HNO3	K2CO3	1.02E-01	5.00E-02	methyl orange	3	24.40	18.03	19.06
2001	HCl	KHCO3	1.00E-01	9.90E-02	methyl orange	2	24.87	28.47	29.82
2002	H2SO4	NaOH	1.25E-01	2.25E-01	methyl orange	2	22.50	48.81	50.05
2003	HCl	X2CO3	2.00E-01	7.80E-02	methyl orange	2	19.45	4.49	5.78
2005	H2SO4	Na2CO3	5.00E-02	4.20E-02	methyl orange	2	21.05	27.67	29.04
2006	HNO3	Na2CO3	1.00E-01	4.57E-02	methyl orange	3	22.85	17.56	18.58
2008	H2X	NaOH	5.00E-02	1.00E-01	Phenolphthalein	2	23.70	40.63	42.01
2009	HCl	X2CO3.10H2O	9.50E-02	8.19E-02		3	43.10	26.27	27.33
2010	NaHSO4	NaOH	1.00E-01	9.16E-02	methyl orange	2	22.90	26.91	28.26
2011	Acid	KOH	1.00E-01	1.22E-01	methyl orange	2	25.20	33.32	34.66
2012	H2Y	NaOH	5.20E-02	9.75E-02	methyl orange	2	23.33	39.57	40.95
2013	H2SO4	XOH	5.00E-02	5.10E-02	methyl orange	2	12.75	29.68	31.05

Table 7: Model response values not approximately equivalent to experimental values

Year	Acid(A)	Base(B)	CA(M)	CB(M)	Indicator	Indicator drops	Exp VA Used (ml)	Model VA used (ml)	Model 2 VA used (ml)
2014	HCl	Na2CO3	1.90E-01	9.20E-02	methyl orange	3	24.10	9.16	10.14
2017	HCl	Na2CO3.10H2O	2.00E-01	1.00E-01	methyl orange	3	24.40	8.87	9.85

5. Conclusion

The advantage of the RSM tool was relied upon in this study to design titration experiments and generate a statistical model in terms of titration parameters predicting the average titre values. The strength of the model was limited to titrations consisting of a monobasic acid, though a high level of success was recorded for the case of redox titration. Further study, is still recommended in that case.

7. References

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