Evaluation of selected halogen anions for the elongation of Leclanche cell's lifespan

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ABSTRACT

The determination of the surface area of manganese dioxide was carried out using adsorption from solution method and was found to be $1702.69 m^2/g$. the adsorption of these anions on manganese dioxide is to enhance the lifespan of Leclanche cell. The adsorption method by potentiometric titration was used for different anions at four different concentrations (1M, 0.1M, and 0.01M) of the salt solutions at varied temperatures of 28^0C, 30^0C and 32^0C. The electric surface charge of the anions at various temperatures and concentrations were also determined. The result showed that blending of some anions particularly Cl^- with manganese dioxide can improve the lifespan of a cell due to its consistency in higher electric surface charge in all concentrations and temperatures.

Keywords: Adsorption; manganese dioxide; potentiometric titration; concentration; Temperature.
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INTRODUCTION

A battery is an electrochemical device that can convert chemical energy into electricity. A battery powers products that require electricity to work(1).

This work is to optimize the adsorption process of the anions namely Cl^-, Br^-, and I^- on a MnO_2 in a Leclanche cell. This is expected to increase the lifespan of the battery, the lifespan of the battery is about 300 seconds on a continuous operation, and this short lifespan increases the rate of replacement of these cells with its attendant consequences to the environment.

The optimum temperature range of operation is between $20 – 50^0C$, outside this temperature range the performance deteriorates markedly (2-3).

During the potentiometric titration experiment, concentration and temperature were varied while other factors were kept constant.

Leclanche cell is a dry cell made up of a zinc case as anode (negative pole) and carbon rod a cathode (positive pole). This battery is filled with a mixture of MnO_2 as an oxidant or depolarizer to lower the internal resistance of the cell and to reduce the evolution of hydrogen which is a byproduct. Leclanche cell are used in low drain appliances such as radios, torches, liquid crystal calculators, toys (4-5).

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The electrolyte is a mixture of NH_4Cl and $ZnCl_2$ (acid electrolyte). The ZnCl2 cannot back zinc corrosion when the cell was inactive. This was a big step for longer battery storage life (6-7).

MATERIALS AND METHODS

Materials
The materials used in this work are chemicals and equipments. The chemicals used in the adsorption from solution experiment for the determination of specific area of manganese dioxide (MnO_2) and that used for the potentiometric titration are sodium hydroxide, acetic acid, phenolphthalein, distilled water, manganese dioxide, sodium chloride, sodium bromide and sodium iodide.

The equipment used in these experiments are 250 ml beaker, 250 ml Erlenmeyer flask with stpper, 50 ml burette, 100 ml titration conical flask, funnel, analytical balance, 25 ml pipette, spatula, fine porosity filter, pH meter, magnetic stirrer/hot plate, magnetic follower, weighing balance, 100 ml beaker, 250 ml conical flask, 250 ml and 1000 ml measuring cylinders, 1000 ml volumetric flask, nitrogen gas cylinder and regulator, tripod stand and clamp, and thermometer.

Methods
Adsorption from solution: This method is used to determine the surface area of MnO_2

Procedure
Seven (7) 250ml Erlenmeyer flask were cleaned and dried. With the aid of analytical balance, 1g of manganese dioxide (MnO_2) was weighed into six of the flasks. 100ml of acetic acid of the following concentrations of 0.15, 0.12, 0.09, 0.06, 0.03 and 0.015M were then added to each of the flasks. Added also to the seventh flask containing no manganese dioxide was 100ml of 0.03 of the acetic acid as a control.

The flasks were then tight fitted with stopper and each shaken for a period of 30 minutes after which they were left over night to allow for equilibrium.

To allow for the determination of the concentration of acetic acid after adsorption, all samples were filtered through fine filter papers with the first 10ml of each filtrate of the different concentration discarded as a precaution against adsorption of the acid by the filter paper.

Using phenolphthalein as indicator in two (different) 25ml portion of each of the different filtrate, was titrated against 0.1m sodium hydroxide to the end point.

From the values of the initial and final concentration of the acetic aid in 100ml of solution, the numbers of moles present before and after adsorption were calculated and numbers of moles N adsorbed were obtained by difference. The values of C/N versus C were plotted and the best lines through these points were drawn. C is the equilibrium concentration. The number of moles per gram Nm required to form a monolayer was then calculated from the slope. On the assumption that adsorption area of acetic acid equals 21 A^2, the area per gram of manganese dioxide (MnO_2) was calculated.

Potentiometric Titration: This method is used to determine the electric surface charge of the anions.

Procedure
100m beaker and 50ml burette were cleansed, dried and rinsed with the respective solution to be placed in them.

To the 100ml beaker, 50ml of 1M solution sodium chloride (NaCl) was measured with a pipette and transferred into the beaker. To provide for a continuous stirring, a magnetic bar was placed inside the beaker. The beaker was then placed on a magnetic stirrer which was connected to a power source (off). A reference electrode and an indicator electrode and an indicator electrode (combined electrode) connected to a pH meter were introduced into the solution in the beaker via electrode holder. A nitrogen gas jet regulated by the gauge from the nitrogen gas cylinder was as well directed into the solution in the beaker such that the gas outlet is immersed in the solution.

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The cleansed burette was filled with 0.1M HNO_3 solution and clamped on a tripod stand such that the tip was directly pointed to the solution in the 100ml beaker.

When the arrangement of the equipment was in order, nitrogen gas regulatory was opened to provide a continuous gas jetting into the solution (bubbling).

To initiate a continuous stirring, the magnetic stirrer was switched on. After a while the reading of the stabilized pH meter without a titrant (HNO_3) was recorded.

Subsequently, 0.5ml of the titrant (HNO_3) was added from the burette and the pH recorded after 60 seconds when the indicator electrode has reached a constant value. The 0.5ml increment and the corresponding pH readings were recorded for a total of 10,0ml additions when no significant change was observed in the pH reading. At the end, both the magnetic stirrer and the pH meter were switched off and the solution mixture disposed.

The process was repeated after the pH meter was stabilized with distilled water, but this time around, 2g of manganese dioxide (MnO_2) was added to the NaCl and the entire process repeated for various concentrations (1, 0.1, & 0.01) at three different temperatures of 28, 30, 32^0C for with and without MnO_2. The temperature was elevated with the aid of a hot plate magnetic stirrer.

The whole procedure was also repeated using NaBr & NaI for the various concentrations of 1, 0.1, & 0.01 at three different temperatures both for with and without Manganese dioxide (MnO_2).

The volumetric readings of 0.1M HNO_3 and their corresponding pH readings for all class of titration carried out were tabulated.

Factorial Experiment Procedure
The experimental data from the potentiometric titration serve as the input for the factorial experiment. The factors for the experimental design were first selected and used as the codes for the factorial analysis as shown in table 1 and 2

Selection of Factors that affects the rate of adsorption
The rate of adsorption of the anions (adsorbents) on the MnO_2 (adsorbate) is affected by; Concentration of the solutions of the anions, Temperature, Degree of agitation or mixing and Mass of the adsorbate.

In this experiment the concentration of the solutions of the anions and the temperature of the solutions were varied whereas the other factors, mass of adsorbate, time of contact and degree of agitation were fixed. The selected factors viz; concentration and temperature, are represented by X_1 and X_2 respectively in Table 2

Development of factorial analysis tables for the surface response
The surface response is developed b factorial method as shown in Tables 1 and 2 below. A 3^2 quadratic equation gives 9 run experiments for the factors; Concentration (x_1) and temperature (X_2). X_0 is base factor selected. The sign + represents maximum value, - represents minimum value and 0 represent average value or interval of the surface response.

In this experiment, a two-variable, three level factorial designs was used. The factor and the code levels are shown in Table 1. Following the column of plus (+), labeled X_0, the next 2 columns (under the headings X_1 and X_2) define the experimental design in the standard order. Thus for Run 1, all 2 variables were set to vary from their highest experimental levels. In actual conduct of the experiment, the run order would generally be randomized.

Table 1: Factors and their coded levels for the anions

		Independent variables	
Levels of factors	Code	X_1 (Conc.)	X_2 (Temperature)
Base level	X_0	0	0
Interval or range	ΔX_0	0.5005	30
High level	+1	1.0	32
Low level	-1	0.001	28

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$$\Delta X_0 = \frac{X\ max + X\ min}{2} \dots\dots\dots\dots\dots 3.1$$

Table 2: Calculation of Matrix and the surface charge (Y) for 3^2 Factorial Design

Run No.	X_0 a_0	X_1 a_1	X_2 a_2	X_{11} a_{11}	X_{12} a_{12}	X_{22} a_{22}	Y Cl^-	Y Br^-	Y I^-
1	+	+	+	+	+	+			
2	+	0	+	0	0	+			
3	+	-	+	+	-	+			
4	+	+	0	+	0	0			
5	+	0	0	0	0	0			
6	+	-	0	+	0	0			
7	+	+	-	+	-	+			
8	+	0	-	0	0	+			
9	+	+	-	+	-	+			

That is, with two variables coded as X_1 and X_2, a 9-run experiment permits unique solutions for the coefficients (parameters) of the equations 3.2 below.

A 2-variable, 3 level factorial arrangements provided the framework for designing the experiment.

The 3^2 arrangement, when applied to only 2 variables, permits uncorrelated, low variance estimates of the 6 coefficients indicated in equation 3.2. The numerical solution of the equation is readily obtained using computer or desk calculator (8-11).

Determination of Model equation of Adsorption
Selection of model equation
A second order equation of the form,

$$Y = f(X_1, X_2) \qquad \dots\dots\dots\dots 3.2$$

$$Y = a_0 + a_1x_1 + a_2 \ x \ x_2 + a_{11}x_1{}^2 + a_{22}x2{}^2 + a_{12}x_1x_2 \ \dots\dots\dots 3.3$$

A 3^2 quadratic factorial equation is selected
Where ai is the coefficient of regression and x_{12} (x_1x_2) is the interaction effect.

RESULTS

Results of the adsorption from the solution

Table 3: Concentration and number of mole adsorbed

Initial concentration of acetic acid C_1(M)	Volume of acetic acid (ml)	Volume of 0.1M NaOH (ml) (average titre)	C	$N = C-C_1$	C/N
0.15	25	44	0.1760	0.026	6.7692
0.12	25	33.5	0.1340	0.014	9.5714
0.09	25	25.65	0.1030	0.013	7.9231
0.06	25	16.3	0.0652	0.0052	12.5385
0.03	25	6.2	0.0248	-0.0052	-4.7692
0.015	25	1.35	0.0054	-0.0096	-0.5625

Results for the potentiometric titration
Tables 4 – 12 are the results of potentiometric titration for all the halogens; Cl^-, Br^-, I^- at 28^0C, 30^0C, and 32^0C for with and without MnO_2

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Table 4: 1M NaCl with and without MnO$_2$ at 28^{0}C, 30^{0}C, and 32^{0}C

Volume of HNO$_3$	NaCl$_2$ at 28^{0}C		NaCl$_2$ at 30^{0}C		NaCl$_2$ at 32^{0}C	
	With MnO$_2$	Without MnO$_2$	With MnO$_2$	Without MnO$_2$	With MnO$_2$	Without MnO$_2$
			PH			
0.0	6.80	8.50	6.71	8.49	6.66	8.38
0.5	6.04	2.85	6.48	3.35	5.89	2.75
1.0	5.81	2.49	6.18	3.00	5.54	2.37
1.5	5.63	2.31	5.97	2.57	5.44	2.18
2.0	5.43	2.15	5.70	2.31	5.23	2.04
2.5	5.37	2.05	5.58	2.12	5.08	1.93
3.0	5.27	1.95	5.51	2.03	4.94	1.83
3.5	5.20	1.87	5.40	1.93	4.85	1.75
4.0	5.09	1.81	5.28	1.87	4.74	1.69
4.5	5.06	1.76	5.16	1.80	5.65	1.64
5.0	4.99	1.72	5.00	1.74	4.52	1.60
5.5	4.96	1.67	4.98	1.70	4.44	1.56
6.0	4.94	1.63	4.74	1.67	4.38	1.56
6.5	4.88	1.61	4.71	1.62	4.31	1.50
7.0	4.83	1.57	4.80	1.59	4.25	1.46
7.5	4.87	1.54	4.77	1.56	4.21	1.42
8.0	4.80	1.52	4.72	1.53	4.16	1.41
8.5	4.75	1.49	4.68	1.50	4.12	1.38
9.0	4.61	1.47	4.65	1.48	4.09	1.35
9.5	4.60	1.45	4.63	1.46	4.07	1.34
10.0	4.59	1.72	4.60	1.43	4.06	1.31
10.5	4.59	1.67	4.60	1.4	4.06	1.31
11.0		1.63		1.40		
11.5		1.61		1.38		
12.0		1.57		1.36		
12.5		1.54		1.36		

Table 5: 0.1M NaCl with and without MnO$_2$ at 28^{0}C, 30^{0}C, and 32^{0}C

Volume of HNO$_3$	NaCl$_2$ at 28^{0}C		NaCl$_2$ at 30^{0}C		NaCl$_2$ at 32^{0}C	
	With MnO$_2$	Without MnO$_2$	With MnO$_2$	Without MnO$_2$	With MnO$_2$	Without MnO$_2$
			PH			
0.0	7.75	6.29	7.80	6.44	7.77	6.07
0.5	7.00	2.85	7.55	2.86	7.31	3.11
1.0	6.67	2.50	6.74	2.58	6.90	2.75
1.5	6.41	2.31	6.38	2.29	6.63	2.48
2.0	6.20	2.16	6.40	2.15	6.58	2.31
2.5	6.10	2.07	6.25	2.07	6.37	2.16
3.0	5.98	1.98	6.06	1.99	6.21	2.08
3.5	5.88	1.93	5.98	1.91	6.14	1.99
4.0	5.79	1.87	5.89	1.84	6.08	1.93
4.5	5.65	1.81	5.78	1.79	5.93	1.87
5.0	5.54	1.77	5.77	1.75	5.83	1.83
5.5	5.43	1.73	5.68	1.70	5.72	1.78
6.0	5.39	1.69	5.56	1.65	5.78	1.74
6.5	5.34	1.65	5.50	1.63	5.72	1.70
7.0	5.25	1.62	5.44	1.61	5.67	1.67
7.5	5.18	1.60	5.38	1.57	5.61	1.64
8.0	5.14	1.57	5.34	1.56	5.56	1.61
8.5	5.10	1.54	5.31	1.53	5.51	1.58
9.0	5.05	1.51	5.28	1.51	5.48	1.55
9.5	5.03	1.50	5.26	1.48	5.45	1.54
10.0	5.02	1.50	5.25	1.46	5.44	1.51
10.5				1.45		1.50
11.0				1.45		

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Table 6 : 0.01M NaCl with and without MnO2 at 28^{0}C, and 32^{0}C

Volume of HNO$_3$	NaCl$_2$ at 28^{0}C		NaCl$_2$ at 30^{0}C		NaCl$_2$ at 32^{0}C	
	With MnO$_2$	Without MnO$_2$	With MnO$_2$	Without MnO$_2$	With MnO$_2$	Without MnO$_2$
				PH		
0.0	9.02	5.75	8.89	5.82	8.92	5.75
0.5	8.71	2.73	8.46	2.75	8.63	2.76
1.0	8.33	2.46	8.14	2.44	8.44	2.50
1.5	8.65	2.31	7.42	2.30	8.26	2.32
2.0	7.67	2.15	7.63	2.15	8.05	2.20
2.5	7.45	2.05	7.11	2.07	7.44	2.07
3.0	6.85	1.97	6.07	1.99	7.42	2.01
3.5	6.66	1.91	6.57	1.91	7.16	1.96
4.0	6.55	1.84	6.34	1.84	6.90	1.89
4.5	6.43	1.79	6.14	1.80	6.73	1.84
5.0	6.35	1.74	5.98	1.76	6.70	1.80
5.5	6.20	1.70	5.79	1.73	6.48	1.76
6.0	6.09	1.66	5.61	1.70	6.38	1.73
6.5	6.01	1.63	5.45	1.66	6.30	1.69
7.0	5.93	1.60	5.38	1.62	6.16	1.66
7.5	5.75	1.56	5.27	1.60	5.99	1.63
8.0	5.65	1.54	5.19	1.56	5.82	1.60
8.5	5.48	1.52	5.13	1.55	5.85	1.58
9.0	5.35	1.50	5.09	1.53	5.65	1.56
9.5	5.28	1.47	5.05	1.51	5.65	1.53
10.0	5.26	1.40	5.03	1.48		1.51
10.5				1.47		

Table 7 : 1M Nal with and without MnO$_2$ at 28^{0}C, 30^{0}C, and 32^{0}C

Volume of HNO$_3$	NaI at 28^{0}C		NaI at 30^{0}C		NaI at 32^{0}C	
	With MnO$_2$	Without MnO$_2$	With MnO$_2$	Without MnO$_2$	With MnO$_2$	Without MnO$_2$
				PH		
0.0	8.12	8.64	8.68	6.54	8.88	6.60
0.5	7.01	2.23	7.81	2.73	8.65	2.83
1.0	6.06	2.04	6.90	2.37	7.40	2.41
1.5	5.80	1.86	6.15	2.11	7.32	2.19
2.0	5.39	1.70	5.75	1.97	6.90	2.02
2.5	5.28	1.62	5.55	1.86	6.88	1.90
3.0	5.13	1.54	5.32	1.77	6.73	1.81
3.5	4.98	1.45	5.18	1.71	6.58	1.72
4.0	4.88	1.40	5.14	1.66	6.38	1.67
4.5	4.79	1.38	5.01	1.60	6.28	1.61
5.0	4.70	1.34	4.89	1.55	6.11	1.56
5.5	4.65	1.30	4.80	1.51	5.91	1.51
6.0	4.60	1.20	4.73	1.46	5.78	1.48
6.5	4.54	1.24	4.68	1.43	5.69	1.45
7.0	4.50	1.22	4.64	1.41	5.60	1.43
7.5	4.44	1.20	4.61	1.39	5.53	1.41
8.0	4.41	1.18	4.58	1.37	5.48	1.39
8.5	4.39	1.16	4.56	1.35	5.44	1.37
9.0	4.37	1.13	4.55	1.34	5.42	1.36
9.5	4.36	1.12	4.53	1.33	5.40	1.35
10.0	4.35	1.11	4.51	1.32	5.38	1.35

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Table 8: 0.1M NaI with and without MnO$_2$ at 28^{0}C, 30^{0}C, 32^{0}C

Volume of HNO$_3$	NaI at 28^{0}C		NaI at 30^{0}C		NaI at 32^{0}C	
	With MnO$_2$	Without MnO$_2$	With MnO$_2$	Without MnO$_2$	With MnO$_2$	Without MnO$_2$
	PH					
0.0	7.61	6.55	7.62	6.44	7.77	6.67
0.5	6.14	2.59	6.43	2.85	6.60	3.63
1.0	5.55	2.28	6.02	2.49	6.02	2.68
1.5	5.27	2.09	5.89	2.25	5.80	2.31
2.0	5.19	1.98	5.76	2.10	5.65	2.17
2.5	5.12	1.84	5.57	1.94	5.46	2.08
3.0	5.02	1.75	5.49	1.91	5.32	1.99
3.5	4.96	1.72	5.41	1.84	5.22	1.91
4.0	4.82	1.64	5.36	1.80	5.11	1.87
4.5	4.78	1.60	5.26	1.76	5.02	1.82
5.0	4.69	1.55	5.12	1.70	4.91	1.76
5.5	7.61	1.52	5.05	1.66	4.88	1.72
6.0	6.14	1.49	4.99	1.63	4.80	1.68
6.5	5.55	1.45	4.80	1.60	4.74	1.65
7.0	5.27	1.42	4.77	1.58	4.69	1.62
7.5	5.19	1.40	4.74	1.56	4.65	1.59
8.0	5.12	1.34	4.72	1.54	4.62	1.57
8.5	5.02	1.32	4.71	1.52	4.60	1.55
9.0	4.96	1.30	4.69	1.50	4.58	1.53
9.5	4.82	1.29	4.67	1.49	4.57	1.52
10.0	4.78	1.29	4.66	1.49	4.56	1.52
10.5	4.78					

Table 9: 0.01M NaI with and without MnO$_2$ at 28^{0}C, 30^{0}C, and 32^{0}C

Volume of HNO$_3$	NaI at 28^{0}C		NaI at 30^{0}C		NaI at 32^{0}C	
	With MnO$_2$	Without MnO$_2$	With MnO$_2$	Without MnO$_2$	With MnO$_2$	Without MnO$_2$
	PH					
0.0	7.11	6.42	8.55	6.31	8.54	6.62
0.5	5.75	2.42	6.88	2.61	6.23	2.70
1.0	5.45	2.22	6.66	2.39	5.94	2.41
1.5	5.30	2.07	6.30	2.21	5.28	2.28
2.0	4.98	1.99	6.20	2.12	5.20	2.16
2.5	4.84	1.93	6.12	2.05	5.13	2.10
3.0	4.68	1.88	5.99	1.98	4.95	2.04
3.5	4.57	1.82	5.76	1.95	4.76	1.95
4.0	4.45	1.78	5.64	1.89	4.60	1.92
4.5	4.36	1.72	5.56	1.86	4.44	1.87
5.0	4.27	1.68	5.47	1.81	4.31	1.82
5.5	4.15	1.66	5.38	1.78	4.16	1.78
6.0	4.08	1.63	5.31	1.72	3.88	1.71
6.5	4.01	1.58	5.24	1.68	3.81	1.68
7.0	3.96	1.56	5.17	1.65	3.73	1.66
7.5	3.93	1.54	5.10	1.57	3.65	1.64
8.0	3.90	1.52	5.05	1.55	3.57	1.60
8.5	3.88	1.50	5.02	1.53	3.50	1.58
9.0	3.85	1.48	5.00	1.51	3.48	1.57
9.5	3.84	1.47	4.99	1.50	3.47	1.55
10.0	3.84	1.47	4.98	1.49	3.47	1.55

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Table 10:1M NaBr with and without MnO$_2$ at 28^{0}C, 30^{0}C, and 32^{0}C

Volume of HNO$_3$	NaBr at 28^{0}C		NaBr at 30^{0}C		NaBr at 32^{0}C	
	With MnO$_2$	Without MnO$_2$	With MnO$_2$	Without MnO$_2$	With MnO$_2$	Without MnO$_2$
				PH		
0.0	6.74	5.71	6.60	5.81	6.86	3.26
0.5	5.21	2.91	5.25	2.50	6.54	3.01
1.0	5.11	2.50	4.95	2.16	6.24	2.74
1.5	4.19	2.28	4.80	1.97	6.12	2.60
2.0	3.98	2.16	4.68	1.82	5.98	2.45
2.5	3.74	2.01	4.53	1.71	5.92	2.37
3.0	3.62	1.93	4.40	1.63	5.89	2.29
3.5	3.45	1.88	4.28	1.58	5.80	2.22
4.0	3.32	1.83	4.13	1.52	5.70	2.15
4.5	3.17	1.76	4.01	1.47	5.63	2.12
5.0	3.06	1.72	3.88	1.43	5.57	2.07
5.5	2.96	1.68	6.60	1.37	5.48	2.03
6.0	2.88	1.64	5.25	1.33	5.44	1.99
6.5	2.81	1.60	4.95	1.30	5.33	1.96
7.0	2.78	1.57	4.80	1.27	5.16	1.94
7.5	2.59	1.55	4.68	1.24	5.13	1.91
8.0	2.55	1.53	4.53	1.22	5.10	1.88
8.5	2.51	1.50	4.40	1.20	4.90	1.86
9.0	2.48	1.48	4.28	1.98	4.80	1.83
9.5	2.46	1.46	4.13	1.97	4.72	1.81
10.0	2.45	1.45	4.01	1.96	4.66	1.79
10.5			3.88		4.60	1.79

Table 11: 0.1M NaBr with and without MnO$_2$ at 28^{0}C, 30^{0}C, and 32^{0}C

Volume of HNO$_3$	NaBr at 28^{0}C		NaBr at 30^{0}C		NaBr at 32^{0}C	
	With MnO$_2$	Without MnO$_2$	With MnO$_2$	Without MnO$_2$	With MnO$_2$	Without MnO$_2$
				PH		
0.0	7.93	6.10	7.77	5.97	7.94	6.04
0.5	6.65	2.83	6.40	2.78	6.46	2.76
1.0	6.23	2.54	5.84	2.56	6.03	2.50
1.5	5.40	2.35	5.70	2.32	5.88	2.39
2.0	5.35	2.22	5.68	2.22	5.71	2.27
2.5	5.25	2.13	5.53	2.07	5.53	2.20
3.0	5.44	2.07	5.46	2.00	5.57	2.12
3.5	5.18	2.50	5.30	1.94	5.40	2.05
4.0	5.08	1.96	5.16	1.86	5.24	1.99
4.5	4.98	1.90	5.07	1.82	5.02	1.87
5.0	4.74	1.86	4.98	1.77	4.88	1.85
5.5	4.65	1.82	4.77	1.72	4.75	1.83
6.0	4.48	1.79	4.69	1.69	4.58	1.81
6.5	4.34	1.75	4.61	1.66	4.44	1.77
7.0	4.29	1.72	4.54	1.63	4.32	1.75
7.5	4.21	1.70	4.46	1.59	3.18	1.72
8.0	4.15	1.68	4.41	1.57	3.10	1.69
8.5	4.09	1.66	4.38	1.55	2.97	1.67
9.0	4.06	1.64	4.35	1.53	2.86	1.66
9.5	4.02	1.62	4.33	1.52	2.85	1.64
10.0	3.98	1.61	4.32	1.51	3.85	1.63
10.5	3.97			1.51		1.63

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Table 12: 0.01M NaBr with and without MnO₂ at 28⁰C, 30⁰C, and 32⁰C

Volume of HNO₃	NaBr at 28⁰C		NaBr at 30⁰C		NaBr at 32⁰C	
	With MnO₂	Without MnO₂	With MnO₂	Without MnO₂	With MnO₂	Without MnO₂
			PH			
0.0	8.64	594	6.28	6.24	9.10	6.38
0.5	6.70	2.85	5.72	2.71	8.22	2.67
1.0	6.40	2.56	5.53	2.45	7.30	2.61
1.5	6.15	2.39	5.38	2.28	6.53	2.45
2.0	5.98	2.29	5.28	2.14	6.28	2.33
2.5	5.74	2.24	5.14	2.07	6.14	2.24
3.0	5.55	2.15	5.06	1.98	6.08	2.17
3.5	5.46	2.06	4.91	1.91	5.98	2.09
4.0	5.35	2.00	4.81	1.84	5.88	2.02
4.5	5.27	1.95	4.72	1.78	5.79	1.96
5.0	5.15	1.92	4.58	1.77	5.47	1.91
5.5	5.05	1.87	4.44	1.74	5.32	1.89
6.0	4.96	1.84	4.32	1.70	5.22	1.85
6.5	4.85	1.81	4.19	1.68	5.14	1.81
7.0	4.77	1.78	4.11	1.65	5.04	1.78
7.5	4.71	1.75	4.05	1.63	4.93	1.76
8.0	4.65	1.72	4.00	1.60	4.85	1.74
8.5	4.58	1.69	3.96	1.58	4.80	1.72
9.0	4.52	1.67	3.93	1.56	4.76	1.69
9.5	4.48	1.65	3.91	1.54	4.74	1.67
10.0	4.47	1.63	3.89	1.54	4.73	1.66
10.5	4.47	1.63				

Analyzed Results

The surface area of Manganese dioxide was determined by adsorption from solution and was found to be 1702.56m^2/g (See Appendix A).

The value of adsorption θ is calculated using Kokarev formula (12). At a given P^H, the difference in volume (ΔV) between the two in each of the P^H against volume was used to calculate the adsorption □.

Results of adsorption and electric surface charge for Cl⁻ (Chloride ion) from NaCl solution
The result obtained for θ and E are presented in tables 13 – 20

Table 13:1M NaCl solution at 28⁰C

pH	ΔV	Adsorption capacity (θ) X10^{-12} (mol/cm^2)	Surface Charge (E) x 10^{-7} (coulombs/cm^2)
4.6	8.7	9.596	9.260
5.0	4.7	5.184	5.003
5.4	1.7	1.875	1.809
6.0	0.3	0.331	0.319
		Average	**4.098**

Table 14:1M NaCl solution at 30⁰C

pH	ΔV	Adsorption capacity (θ) X10^{-12} (mol/cm^2)	Surface Charge (E) x 10^{-7} (coulombs/cm^2)
4.6	8.6	9.486	9.154
4.8	5.6	6.171	5.955
5.4	3.3	3.640	3.513
6.0	1.2	1.324	1.277
6.4	0.4	0.441	0.426
		Average	**4.975**

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Table 15:1M NaCl solution at 32^0C

pH	ΔV	Adsorption capacity (θ) $X10^{-12}$ (mol/cm^2)	Surface Charge (E) x 10^{-7} (coulombs/cm^2)
4.4	5.4	5.956	5.748
4.6	4.5	4.964	4.780
5.0	2.7	2.978	2.874
5.6	0.8	0.882	0.852
		Average	**3.566**

Table 16: 0.1M NaCl solution at 28^0C

pH	ΔV	Adsorption capacity (θ) $X10^{-12}$ (mol/cm^2)	Surface Charge (E) x 10^{-7} (coulombs/cm^2)
5.0	8.8	9.706	9.367
5.4	7.5	8.273	7.983
5.8	4.0	4.412	4.258
6.2	2.0	2.206	2.129
		Average	**5.934**

Table 17: 0.1M NaCl solution at 30^0C

pH	ΔV	Adsorption capacity (θ) $X10^{-12}$ (mol/cm^2)	Surface Charge (E) x 10^{-7} (coulombs/cm^2)
5.2	9.5	10.48	10.11
5.6	5.9	6.508	6.280
6.0	3.0	3.309	3.193
6.4	1.5	1.655	1.597
		Average	**5.295**

Table 18: 0.1M NaCl solution at 32^0C

pH	ΔV	Adsorption capacity (θ) $X10^{-12}$ (mol/cm^2)	Surface Charge (E) x 10^{-7} (coulombs/cm^2)
5.5	8.5	9.376	9.047
5.6	7.4	8.162	7.877
5.8	5.0	5.515	5.322
6.0	4.2	4.633	4.470
		Average	**6.679**

Table 19: 0.01M NaCl solution at 28^0C

pH	ΔV	Adsorption capacity (θ) $X10^{-12}$ (mol/cm^2)	Surface Charge (E) x 10^{-7} (coulombs/cm^2)
5.2	9.8	10.81	10.43
5.4	8.8	9.706	9.367
5.6	8.0	8.824	8.515
5.8	7.2	7.942	7.664
		Average	**8.994**

Table 20: 0.01M NaCl solution at 30^0C

pH	ΔV	Adsorption capacity (θ) $X10^{-12}$ (mol/cm^2)	Surface Charge (E) x 10^{-7} (coulombs/cm^2)
5.2	7.9	8.714	8.409
5.4	6.5	7.140	6.919
5.6	6.0	6.618	6.386
5.8	5.5	6.067	5.854
		Average	**6.892**

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Results of Adsorption and surface electric charge for Br⁻ (bromide ion) from NaBr solution.
The results obtained for θ and E are presented in tables 21 – 29

Table 21: 1M NaBr solution at 28⁰C

pH	ΔV	Adsorption capacity (θ) $X10^{-12}$ (mol/cm²)	Surface Charge (E) x 10^{-7} (coulombs/cm²)
2.8	5.9	6.508	6.280
3.2	4.0	4.412	4.258
4.0	1.7	1.875	1.809
5.0	1.0	1.103	1.064
		Average	**3.353**

Table 22: 1M NaBr solution at 30⁰C

pH	ΔV	Adsorption capacity (θ) $X10^{-12}$ (mol/cm²)	Surface Charge (E) x 10^{-7} (coulombs/cm²)
3.2	9.1	10.04	9.686
4.0	4.2	4.633	4.470
4.6	2.2	2.427	2.342
5.0	0.9	0.993	0.953
5.2	0.4	0.441	0.426
		Average	**6.067**

Table 23: 1M NaBr solution at 32⁰C

pH	ΔV	Adsorption capacity (θ) $X10^{-12}$ (mol/cm²)	Surface Charge (E) x 10^{-7} (coulombs/cm²)
3.8	4.4	4.853	4.683
4.6	2.6	2.868	2.767
5.2	1.35	1.489	1.437
5.8	0.4	0.441	0.426
		Average	**3.286**

Table 24: 0.1M NaBr solution at 28⁰C

pH	ΔV	Adsorption capacity (θ) $X10^{-12}$ (mol/cm²)	Surface Charge (E) x 10^{-7} (coulombs/cm²)
4.2	7.2	7.942	7.664
5.0	4.37	4.820	4.651
5.4	1.4	1.544	1.490
6.0	1.2	1.324	1.277
		Average	**3.771**

Table 25: 0.1M NaBr solution at 30⁰C

pH	ΔV	Adsorption capacity (θ) $X10^{-12}$ (mol/cm²)	Surface Charge (E) x 10^{-7} (coulombs/cm²)
4.4	7.4	8.167	7.877
5.0	5.67	6.254	6.035
5.4	3.2	3.530	3.406
5.8	1.0	1.103	1.064
		Average	**4.596**

Table 26: 0.1M NaBr solution at 32⁰C

pH	ΔV	Adsorption capacity (θ) $X10^{-12}$ (mol/cm²)	Surface Charge (E) x 10^{-7} (coulombs/cm²)
4.0	8.1	8.934	8.622
4.6	5.8	6.397	6.173
5.2	3.9	4.302	4.151
5.8	1.8	1.985	1.916
		Average	**5.216**

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Table 27: 0.01M NaBr solution at 28⁰C

pH	ΔV	Adsorption capacity (θ) X10^{-12} (mol/cm^2)	Surface Charge (E) x 10^{-7} (coulombs/cm^2)
4.8	6.4	7.059	6.812
5.2	4.7	5.184	5.003
5.6	3.0	3.309	3.193
5.8	2.4	2.647	2.555
		Average	**4.391**

Table 28: 0.01M NaBr solution at 30⁰C

pH	ΔV	Adsorption capacity (θ) X10^{-12} (mol/cm^2)	Surface Charge (E) x 10^{-7} (coulombs/cm^2)
4.6	4.7	5.184	5.003
5.0	3.17	3.497	3.374
5.4	1.4	1.544	1.490
5.8	0.4	0.441	0.426
		Average	**3.531**

Table 29: 0.01M NaBr solution at 32⁰C

pH	ΔV	Adsorption capacity (θ) X10^{-12} (mol/cm^2)	Surface Charge (E) x 10^{-7} (coulombs/cm^2)
4.8	7.8	8.603	8.302
5.2	5.87	6.475	6.248
5.8	4.4	4.853	4.683
6.2	2.2	2.427	2.342
		Average	**5.394**

Results of Adsorption and electric surface charge for I⁻ (iodide ion) from NaI solution
The results obtained for θ and E are presented in Tables 30 – 38

Table 30: 1M NaI solution at 28⁰C

pH	ΔV	Adsorption capacity (θ) X10^{-12} (mol/cm^2)	Surface Charge (E) x 10^{-7} (coulombs/cm^2)
4.4	7.05	7.776	7.504
5.0	3.2	3.530	3.406
5.8	1.3	1.434	1.386
6.4	0.6	6.618	6.386
		Average	**4.670**

Table 31: 1M NaI solution at 30⁰C

pH	ΔV	Adsorption capacity (θ) X10^{-12} (mol/cm^2)	Surface Charge (E) x 10^{-7} (coulombs/cm^2)
4.8	7.3	8.052	7.770
5.2	3.3	3.640	3.513
5.8	2.0	2.206	2.129
6.2	1.3	1.434	1.384
		Average	**3.699**

Table 32: 1M NaI solution at 32⁰C

pH	ΔV	Adsorption capacity (θ) X10^{-12} (mol/cm^2)	Surface Charge (E) x 10^{-7} (coulombs/cm^2)
5.4	8.27	9.122	8.803
5.8	5.9	6.508	6.280
6.2	4.4	4.853	4.683
6.5	3.8	4.191	4.045
		Average	**5.953**

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Table 33: 0.1M NaI solution at 28⁰C

pH	ΔV	Adsorption capacity (θ) X10⁻¹² (mol/cm²)	Surface Charge (E) x 10⁻⁷ (coulombs/cm²)
4.6	5.4	5.956	5.748
5.0	2.8	3.088	2.980
5.6	0.9	0.992	0.958
6.2	0.5	0.552	0.532
		Average	**5.908**

Table 34: 0.1M NaI solution at 30⁰C

pH	ΔV	Adsorption capacity (θ) X10⁻¹² (mol/cm²)	Surface Charge (E) x 10⁻⁷ (coulombs/cm²)
4.8	6.3	6.949	6.706
5.4	3.37	3.717	3.587
5.8	1.8	1.985	1.916
6.2	0.8	0.882	0.852
		Average	**5.181**

Table 35: 0.1M NaI solution at 32⁰C

pH	ΔV	Adsorption capacity (θ) X10⁻¹² (mol/cm²)	Surface Charge (E) x 10⁻⁷ (coulombs/cm²)
4.8	5.9	6.508	6.280
5.4	2.6	2.868	2.767
5.8	1.37	1.511	1.458
6.2	0.7	0.772	0.745
		Average	**4.489**

Table 36: 0.01M NaI solution at 28⁰C

pH	ΔV	Adsorption capacity (θ) X10⁻¹² (mol/cm²)	Surface Charge (E) x 10⁻⁷ (coulombs/cm²)
4.0	6.1	6.728	6.493
4.6	3.0	3.309	3.193
5.2	1.57	1.732	1.671
6.0	0.4	0.441	0.426
		Average	**3.904**

Table 37: 0.01M NaI solution at 30⁰C

pH	ΔV	Adsorption capacity (θ) X10⁻¹² (mol/cm²)	Surface Charge (E) x 10⁻⁷ (coulombs/cm²)
5.0	8.27	9.122	8.803
5.4	5.1	5.625	5.428
5.8	3.5	3.861	3.725
6.2	2.0	2.206	2.129
		Average	**5.021**

Table 38: 0.01M NaI solution at 32⁰C

PH	ΔV	Adsorption capacity (θ) X10⁻¹² (mol/cm²)	Surface Charge (E) x 10⁻⁷ (coulombs/cm²)
3.8	6.0	6.618	6.386
4.6	3.73	4.114	3.970
5.6	1.27	1.401	1.352
6.2	0.4	0.441	0.426
		Average	**3.992**

Statistical Results

The factorial analyzed results are also presented in Tables 39 – 45

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Table 39: Factorial Result for Cl⁻ (chloride ion) as NaCl

Degree of Freedom	X_0	X_1	X_2	$Y \times 10^{-3}$ (Coulombs/m²)
1	+	+	+	0.357
2	+	0	+	0.178
3	+	-	+	0
4	+	+	0	0.498
5	+	0	0	0.367
6	+	-	0	0.237
7	+	+	-	0.410
8	+	0	-	0.687
9	+	-	-	0.965

Table 40: Factorial Result for Br⁻ (Bromide ion) as NaBr

Degree of Freedom	X_0	X_1	X_2	$Y \times 10^{-3}$ (Coulombs/m²)
1	+	+	+	0.329
2	+	0	+	0.276
3	+	-	+	0.224
4	+	+	0	0.607
5	+	0	0	0.455
6	+	-	0	0.302
7	+	+	-	0.335
8	+	0	-	0.532
9	+	-	-	0.729

Table 41: Factorial Result for I⁻ (Iodide ion) as NaI

Degree of Freedom	X_0	X_1	X_2	$Y \times 10^{-3}$ (Coulombs/m²)
1	+	+	+	0.595
2	+	0	+	0.462
3	+	-	+	0.329
4	+	+	0	0.370
5	+	0	0	0.352
6	+	-	0	0.333
7	+	+	-	0.467
8	+	0	-	0.423
9	+	-	-	0.380

Table 42: Calculation of Matrix and the Surface Charge (E) of the Anions E = Y x 10⁻⁷ (Coulombs/cm²) for 3²
Factorial Design

Run No	X_0 a_0	X_1 a_1	X_2 a_2	X_{11} a_{11}	X_{12} a_{12}	X_{22} a_{22}	Y Cl⁻	Y Br⁻	Y I⁻
1	+	+	+	+	+	+	3.566	3.286	5.953
2	+	0	+	0	0	+	1.783	2.761	4.623
3	+	-	+	+	-	+	0	2.236	3.292
4	+	+	0	+	0	0	4.975	6.067	3.699
5	+	0	0	0	0	0	3.672	4.545	3.517
6	+	-	0	+	0	0	2.368	3.023	3.334
7	+	+	-	+	-	+	4.098	3.353	4.670
8	+	0	-	0	0	+	6.874	5.322	4.234
9	+	+	-	+	-	+	9.650	7.291	3.797

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Determination of regression coefficients of the model equation

Table 43: Determination of Significance of Data for Cl^-

Obs	X_1	X_2	Significance of variance = 2 Y
1	1	32	3.566
2	1	32	1.783
3	1	32	0
4	0.501	30	4.975
5	0.501	30	3.672
6	0.501	30	2.368
7	0.001	28	4.098
8	0.001	28	6.874
9	0.001	28	9.650

Table 44: Determination of Significance of data for Br^-

Obs	X_1	X_2	Significance of variance = 1 Y
1	1	32	3.286
2	0.501	32	2.761
3	1	32	2.236
4	1	28	6.067
5	0.501	30	4.545
6	1	30	3.023
7	0.501	28	3.353
8	1	32	5.322
9	0.501	32	7.291

Table 45: Determination of significance of data for I^-

Obs	X_1	X_2	Significance of variance = 2 Y
1	1	32	5.953
2	1	32	4.623
3	1	32	3.292
4	0.501	30	3.699
5	0.501	30	3.517
6	0.501	30	3.334
7	0.001	28	4.670
8	0.001	28	4.234
9	0.001	28	3.797

RESULTS AND DISCUSSION

Determination of Surface Area of MnO_2
The volumetric analysis (titration) between various concentration of acetic acid including a control show a gradual increase in the titre valve 0.1M NaOH thus reflecting in the increase in the concentration of acetic acid. A plot of C/N versus C gave a straight line graph and the slope Nm was used to calculate the surface area of MnO_2. The surface area of MnO2 was found to be $1702.69 m^2/g$.

Effect of Concentration of Anions on Adsorption (□)
The result showed that the lower the concentration of the anions the higher the adsorption of the anions. This is a complete deviation from the fact that the higher the concentration of the anions (greater gradient) the higher the adsorption of the adsorbate. The fact is that the higher the concentration of the anions the less the kinetic energy of the anions and the chances of being adsorbed with time. However, the lower the concentration of the anions the higher the chances of being adsorbed as a result of lesser concentration of the anions.

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Effect of Concentration and Temperature of anions on Surface Charge (E)
The lower the concentration of the anions the higher the surface charge posed on the MnO_2. Similarly, the surface charge of different concentration of anions with respect to a selected temperature of 30^0C shows that

C1: 0.01M>0.1M>1M
Br:1M>0.1M>0.01M
I: 0.1M >0.01M>1M

The surface charge of some concentration of anions at 30^0C show that

Form 1M, $Br^- > Cl^- > I^-$
For 0.1M. $Cl^- > I^- > Br^-$
For 0.01M. $Cl^- > I^- > Br^-$

The above comparism shows that the surface charges of Cl^- is higher than all the selected halogen anions namely Br^- and I^- for all the concentrations.

Effect of pH on MnO_2
As the titration proceeds with additional volume of the titrant, a sudden but gradual decrease of the pH solution with MnO_2 was observed. The pH value ends towards greater acidity. Generally, the starting pH values of the titrant in each of the concentration of the anion, is greater with MnO_2 than those without MnO_2. This is because the MnO_2 is alkaline in nature.

The plot of pH against the volume of titrant HNO_3 showed that those without MnO_2 fall below those with MnO_2, this is because the addition of MnO_2 into the titrant results in increase in pH value but this suddenly decreases as the hydrogen ions of the titrant get absorbed unto the MnO_2 thereby decreasing the anion concentration from the solution making the solution tends towards acidity due to less anions in the solution. At a stage there will be no further change in the pH values. This is possible because when all the adsorption sites have been fully covered by the anions, further addition will not yield any change in the pH values of both the solutions of with and without MnO_2.

The Result of Regression Analysis
In statistical analysis attempt was made to discover and establish relationship between the different variables such as pH, temperature and concentration involved in the analysis.

To this effect the chapter served as an attempt to evaluate the determination of surface electric charge of anions. This was done by checking the type of relationship that exists between the dependent variable (Chloride, Bromide and Iodide) and concentration of the Anions and Temperature of the anions. This was done through the use of regression analysis. The computational device is the statistical package (SPSS) software programme.

The result of the regression model equation for Cl^-
$Y_{c1^-} = 98.2619 + 2.56224x_1 + 0.1642x_2 + 0.4306x_{12}$

This model equation is statistically insignificant with p-value of 0.058 which is slightly > 0.050.

The result of the regression model equation for Br^-
$Y_{Br} = 80.6951 - 1.0034x_1 + 0.1652x_2 - 0.1658x_{12}$

P – Value = 0.6911 is statistically insignificant interaction.

The result of the regression model equation for I^-
$Y_1 = 104.9618 + 3.6541x_1 + 0.2279x_2 + 0.8328x_{12}$

P-value = 0.3125 which means statistically insignificant interaction.

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CONCLUSION

The result obtained and its analysis showed that; The surface area of MnO_2 was found to be 1702.69m2/g, and manganese dioxide (MnO_2) used as a depolarizer in a dry cell can be improved if properly blended with alkaline anions especially Cl^- ion. The is because their presence will increase the surface charges which in effect result in enhanced voltage output and extension of cells lifespan due to its greater surface charge. The investigation showed that the use of Cl^- ion can be justified because of its consistent increase in its surface charges at different concentrations and temperature compared with Br^- and I^-. The adsorption of these anions on the MnO_2 as a depolarizer will increase the lifespan of Leclanche cell in the following decreasing order; Cl^- (48%) > Br^- (12%) > I^- (10%).

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APPENDIX A

Determination of surface Area of MnO2 by adsorption from solution
i. Concentration of the given stock of acetic acid

C_c =   (% Purity x S.G x 1000)/(M.wt $\times$ 100) …………….. (1)

Where C_c = concentration of stock acetic acid, % purity = percentage purity of stock acetic acid, S. G = specific gravity of stock acetic acid, M. wt = molecular weight of acetic acid.

The assays on the stock bottle of acetic acid are: S. G = 1.0495, m.wt = 60.05g.
% Purity = 99%

Using (1) above, we have; C_c =   (99 x 1.0495 x 1000)/(60.05 x 100) =   17.3M

ii. To obtain the volume of stock acid solution required to be made up to 1000ml, in order to have 0.15M acetic acid

solution, the relation; $C_cV_c = C_d V_d$ …………………………….. (2)

Where C_c = concentration stock acetic acid (M), V_c = volume (ml) of stock acid solution required dilution, C_d = Desired concentration of needed acetic acid solution, V_d = Volume of desired acid solution.
Applying (2)

$C_cV_c = C_d V_d$;   Where C_d = 17.3M, V_c = ?, V_d = 100ml

17.3 x V_c = 0.15 x 1000; V_c = (0.15 x 1000)/17.3 = 8.67ml

Therefore 8.67ml of the given stock acetic acid is required to be measured and made up to 100ml of solution to obtain 0.15M acetic acid solution needed. Also, 0.12, 0.9, 0.09, 0.06, 0.03 and 0.015M acetic acid were obtain by respectively making up 80, 60, 40, 20 and 10ml of 0.15M acetic acid solution up to 100ml with distilled water.

iii. Calculation of equilibrium concentration of acetic acid after adsorption from solution
The final concentration (equilibrium concentration) of acetic acid is determined from the results of its titration with 0.1M NaOH.

Considering the stoichiometric expression below;

$CH_3COOH + NaOH$ = $CH_3COONa + H_2O$
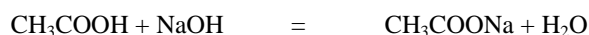
We have that; $C_AV_A/ C_BV_B = n_a/ n_b$ …………………….(3)

Where C_A= Final concentration of acetic acid, V_A = Volume of acetic acid used = 25ml, C_B = Concentration of NaOH = 0.1M, V_B = Average Titre (ml), n_a = number of moles of acid = 1, n_b = number of moles of base = 1.

From (3) $C_A V_A = C_B V_B$; C_A = $C_B V_B/ V_A$ ………………………..(4)

By applying (4); For 0.15M solution of acetic acid:

C_A =   (0.1 x 44)/ 25 = 0.1760
For 0.12M: C_A = (0.1 x 33.5)/ 25   =   0.1340M; For 0.09M: C_A = (0.1 x 25.65)/ 25   =   0.103M
For 0.06M: C_A = (0.1 x 16.3)/ 25   = 0.0652M; For 0.03M C_A = (0.1 $\times$ 6.2)/25   =   0.0248M
For 0.015M C_A =(0.1 x 1.35)/25   =   0.0054M

The initial concentration of acetic was labeled as C_1 while the final concentrations were labeled as C.

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iv. Calculation of slope from the graph of C/N against C.
Slope = $\Delta y/ \Delta x$ = $(y_2 - y_1)/(x_2 - x_1)$ = $(8.6 - 6)/(0.125 - 0.09)$ = 2.6/0.035 = 74.286
From the equation plotted i.e. $C/N = C/N_m + 1/kN_m$

Slope = 1/Nm N_m = 1/slope = 1/74.286 = 0.01346076

v. Calculation of specific area, A.
The specific area, A (in m2/g) for adsorption is given by

$A = N_m N_o o \times 10^{-20}$

Where N_m = Number of adsorption sites = 0.01356076, N_o = Avogadro's number = 6.023 x 1023, o= Area occupied by an adsorbed molecule on the surface   =   21A

Therefore: A   =   0.01346076 x 6.023 x 10^{23} x 21 x 10^{-20} =   1702.55731m^2/g = 1702.56m2/g