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# ADSORPTION OF HEAVY METALS (LEAD ION) FROM INDUSTRIAL WASTE WATER USING ACIDIFIED BENTONITE CLAY

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**Abstract**— The adsorption potential of acidified bentonite clay obtained from Adamawa state; a location in North Eastern Nigeria was investigated through batch experiments conducted to remove  $Pb^{2+}$  from an aqueous solution. A constant weight of 0.5g of acidified bentonite clay was used throughout the experiment.  $Pb^{2+}$  adsorption was found to be dependent on initial concentration, contact time, temperature and pH. An initial metal ion concentration of 50ppm and 10ppm gave maximum uptake (99%) and minimum uptake (87%) respectively. Temperatures of 70 o C and 50 o C altered the adsorption; giving (99.75%) and (96.2%) as maximum and minimum uptakes respectively. A 99.93% adsorption was recorded as maximum at contact time of 10.0 min while 95.79% was the minimum at 40.0 min. At pH level of 6.0, adsorption was maximum (98.8%) and minimum (89.8%) when pH was reduced to 4.0. Experimental isotherm data were analyzed using the Langmuir, and Freundlich equations. The kinetic processes of  $Pb^{2+}$  adsorption on the bentonite clay were described by applying pseudo-first order and pseudo-second order rate equations. The kinetic data for the adsorption process obeyed pseudo-second order rate equations.  $R^2$  was used to enhance the justification analysis for each used model (1st order:  $R^2 = 0.423$ , 2nd order:  $R^2 = 1$ , intra particle diffusion model:  $R^2 = 0.997$ ). The acidified bentonite clay investigated in this study exhibited a high potential for the removal of  $Pb^{2+}$  from aqueous solution.

**Keywords** - Bentonite Clay, Beneficiation, Heavy metals, waste water.

## I. INTRODUCTION

Environmental pollution is becoming a great concern and better technologies for wastewater treatment are being tested. The availability of cheaper and more efficient adsorbents have led to more research in the area of effective and economic adsorption process. One of these areas of research according to Ming Qin J et al. (2009) focuses on cation exchange resins, such as clay, to abate wastes from contaminated water. Generally, Industrial discharge is the major cause of contamination to the environment (Kadirvelu et al. 2003). Wastewater consist mainly

of oxygen- demanding materials, grease, oil, scum, pathogenic bacteria, viruses, pesticides, refractory organic compounds and heavy metals (Grassi et al. 2012).

### A. Bentonite Clay

Bentonite is an aluminum phyllosilicate clay consisting primarily of montmorillonite. The name was given by Wilbur C. Knight in 1898 after the Cretaceous Benton Shale close to Rock River, Wyoming (Hosterman and Patterson, 1992). The various types of bentonites were each named after their respective dominant element; potassium (K), sodium (Na), calcium (Ca), and aluminum (Al). Bentonite is widely used in manufacturing of paints, greases, oil-based drilling mud, cosmetics, pharmaceuticals, detergents, paper and in wastewater treatment. The demand for bentonite depends majorly on the growth of end-user industries that utilize it to produce various products. Hence, future demand for bentonite is dependent on growth of the national economy, especially the manufacturing sector (Gutierrez and Fuentes, 1996).

### B. Heavy Metals in Industrial Wastewater

Toxic metals ions find their way into water bodies through wastewater discharge from metal plating industries and factories of batteries, mining, and pigments. They are present in the environment in different forms; the most common forms are chloride, oxides and nitrate (Kadirvelu et al. 2003). Other common sources include: wastewaters of electroplating, leather tanning, cement, petrochemical, refinery and paint industries. Heavy metals are removed by precipitation, membrane separations, solvent extraction etc. These techniques are challenged by the removal of lower concentrations of metals from solution. Alternatively, adsorption is a simple, selective and economic process for removing heavy metal ions from wastewater (Kadirvelu et al. 2003). This may be due to the simplicity, effectiveness, low cost and abundance of adsorbents like bentonite clay. Wastewater treatment with bentonite is based on its ion exchange and adsorption mechanisms, with relatively high cation exchange capacity (CEC) and specific surface area. Bentonite holds pollutants and prevents downward movement of wastewater. It is therefore important to know the retention capacity of bentonite alongside the factors that govern cation retention (Ming Qin J et al. 2009). Heavy metals are



metals or metalloid having high density, and known for their toxicity. They include; lead, chromium, cadmium, nickel, mercury etc. these Heavy metals are natural constituent of the environment. World Health Organization (WHO) specifies the maximum allowable concentration of heavy metals that should be present in any eatable and drinkable substances as 0.005g/L (WHO, 2011; Bosch et al., 2016). Intake of heavy metal like arsenic can cause cancer of the skin and pulmonary diseases when taken above the WHO recommendations. Toxicity depends on several factors including the dose, route of exposure, and chemical species, as well as the age, gender, genetics, and nutritional status of exposed individuals. As a result of their high level of toxicity, arsenic, cadmium, chromium, lead, and mercury rank among the priority metals that are of public health significance (Lenntech, 2012; Asli Baysal et al. 2013). The known fatal effects of heavy metal toxicity in drinking water include damages or reduced mental and central nervous function and lower energy level. They also cause irregularity in blood composition, acute and chronic effect on vital organs such as kidneys and liver. (Sher Ali Khan et al., 2011).

## II. MATERIALS AND METHODS

### A. Materials

The materials used for this research work include: Bentonite clay, wastewater (Simulated), Portable water, Deionized water.

### B. Equipment's and Apparatus

The equipment's used for this research work includes: Ceramic and wooden mortars and pestles, Weighing balances, Digital stop watch, Plastic containers, Sieve (63 $\mu$ m), Crucibles, Beakers, Volumetric flask and Measuring cylinders others are Magnetic stirrer, Digital water bath, Filter paper, Sample bottles, X-Ray fluorescence (XRF) machine, BET analysis machine and Atomic Adsorption Spectrophotometer (AAS).

### C. Sample Collection

The bentonite clay sample was collected from Adamawa State, North-East of Nigeria.

### D. Sample Preparation

#### a. Beneficiation Process

The raw bentonite clay lumps sample was obtained from Adamawa State, North East Nigeria and sun dried to reduce moisture content and enhance grinding. The surface area of the bentonite sample was reduced to enhance drying of the sample. The clay lumps was crushed down to coarse powder form using wooden mortar and pestle. 10kg of the coarse powder was weighed and soaked in 90 litres of portable water in plastic container and the mixture was allowed to stay overnight (24 hours) to properly dissolve. The mixture was agitated (stirred) for 3 hours at room temperature to separate bonded clay from clay minerals and allow the clay to mix with water. The stirred mixture was allowed to remain in the container overnight (24 hours). The mixture was then plunged for another 3 hours at room temperature for proper separation of bonded clay with quartz and clay minerals. The stirred mixture was allowed to remain in the container for 24 hours for the coarse quartz impurities to sediment to the bottom leaving colloidal solution of bentonite at the top. The solution was sieved through a 23mesh

Tyler sieve (63 $\mu$ m sieve opening) and the quartz washed to recover clay, then the clay solution allowed to settle for 120 hours (5 days) to allow the bentonite sediment and thicken at the bottom of the container. The thicken bentonite was scrubbed to a filter clothe and pressed under a hydraulic press for 72 hours (3 days) to squeeze out the water content. The resulting cake was kneaded into small lumps and air-dried using a trampoline at room temperature. The sample was later Sun-dried and oven dried at 120°C to a constant weight, broken down to powder for subsequent experiment. The beneficiation process was allowed for 19 days to complete.

#### b. Calcination of the Beneficiated Bentonite Clay

150g of the beneficiated clay was fired gradually in an electric furnace to 700°C and soaked at that temperature for 3 hours. The calcined clay was allowed to cool and analyzed.

#### c. Acidification of the Calcined Bentonite

20g of the clay calcined was treated with HCl acid using wet methods. Preparations were made, but this time the bentonite was soaked in 3M of HCl acid solution and stirred, filtered and the residue dried. The acidified clay sample was taking for XRF, and BET analysis to determine the chemical composition of the clay and surface area respectively.

### E. Preparation of Stock Solution

A 1.5985g of Pb(NO<sub>3</sub>)<sub>2</sub> was dissolved in 1000mls volumetric flask and diluted with deionized water to the mark. This gave 1000ppm of Lead stock solution. 10mls of the stock solution was measured using the measuring cylinder and poured into a 1000mls volumetric flask which is then diluted to the mark to give a solution of 10ppm of Lead (II). From the stock solution, 20ppm, 30ppm, 40ppm and 50ppm was prepared the same way as the 10ppm. These was then used for the adsorption experiment.

### F. Sorption Experiment

Batch investigation was conducted by varying the following process parameters; initial metal ion concentration, contact time, temperature and pH respectively.

#### a. Effect Initial Metal Ions Concentration

50mls of Lead solution of concentration 10ppm was added to 0.5g of bentonite and stirred for 30minutes after which it was filtered and the filtrate stored in the sample bottle for AAS analysis. The process was repeated for metal ion concentration of 20ppm, 30ppm, 40ppm and 50ppm respectively.

#### b. Effect of Contact Time on Adsorption

50mls of Lead solution of concentration 30ppm was added to 0.5g of bentonite and then stirred for 10minutes after which it was filtered and the filtrate stored in the sample bottle for AAS analysis.

The process was repeated for contact time of 20minutes, 30minutes, 40minutes and 50minutes.



**c. Evaluation of the Adsorptive Capacity of Acidified Bentonite Clay**

In this study, the adsorption capacity of the acidified-bentonite clay towards the removal of the Pb (II) ion, the effects of concentration of adsorptive solution, temperature, contact time, and pH of the solutions were investigated.

The amount of adsorbed metal ion can be calculated using equation 1 and 2.

$$\% \text{ Amount adsorbed} = (Q_i - Q_f) / Q_i \times 100 \quad \dots (1)$$

$$Q_e = (Q_i - Q_f) V / m \quad \dots (2)$$

where

$Q_e$  = metal ion uptake (sorption capacity) in mg/g

$Q_i$  = initial metal ion concentration in mg/l

$Q_f$  = final metal ion concentration in mg/l

$V$  = 50ml

$m$  = 0.5g

**d. Effect of Temperature on Adsorption**

50mls of Lead solution of concentration 30ppm was added to 0.5g of bentonite and then stirred for 30minutes at 30°C in a digital water bath after which it was filtered and the filtrate stored in the sample bottle for AAS analysis. The process was repeated for temperature of 40°C, 50°C and 60°C and 70°C.

**e. Effect of pH on Adsorption**

50mls of Lead solution of concentration 30ppm was added to 0.5g of bentonite and then stirred for 30minutes at pH of 4.0 after which it was filtered and the filtrate stored in the sample bottle for AAS analysis. The process was repeated for pH of 6.0, 9.0, 11.0, and 12.0.

**III. RESULTS**

**Table 3.1: Chemical Composition of Acidified Bentonite Clay using XRF.**

Element	Composition (wt %)
Al	15.5
Si	50.6
K	8.82
Ca	1.79
Ti	1.89
V	0.078
Cr	7.08
Mn	0.17
Fe	13.42
Cu	0.029
Zn	0.043
Ga	0.038
Au	0.17
Eu	0.26
Re	0.1
<b>Total</b>	<b>99.988</b>

**Table 3.2: Bet Analysis**

Parameters	Values
Micropore volume (cm <sup>3</sup> /g)	1.746
Micropore area (m <sup>2</sup> /g)	1424.3

**Table 3.3: Effect of initial metal ion concentration on Adsorption**

$Q_i$ (ppm)	$Q_f$ (ppm)	Amount adsorbed (ppm)	% Amount adsorbed	$Q_e$ (ppm)
10.0	1.2995	8.7005	87.0050	870.0500
20.0	ND	-	-	-
30.0	0.7685	29.2315	97.4383	2923.1500
40.0	ND	-	-	-
50.0	0.4103	49.5897	99.1794	4958.9700

**Table 3.4: Effect of Temperature on adsorption**

Temperature variation (min)	$Q_f$ (ppm)	Amount adsorbed (ppm)	% Amount adsorbed	$Q_e$ (ppm)
30.0	0.5052	29.4948	98.3160	2949.4800
40.0	0.1634	29.8366	99.4553	2983.6600
50.0	1.1448	28.8552	96.1840	2885.5200
60.0	ND	-	-	-
70.0	0.0742	29.9258	99.7527	2992.5800

**Table 3.5: Effect of Contact Time on Adsorption**

Time variation (min)	$Q_f$ (ppm)	Amount adsorbed (ppm)	% Amount adsorbed	$Q_e$ (ppm)
10.0	0.0211	29.9789	99.9297	2997.8900
20.0	ND	-	-	-
30.0	0.9842	29.0158	96.7193	2901.5800
40.0	1.2623	28.7377	95.7923	2873.7700
50.0	ND	-	-	-



Table 3.6: Effect of pH on Adsorption

pH Variation	Q <sub>f</sub> (ppm)	Amount adsorbed (ppm)	% Amount adsorbed	Q <sub>e</sub> (ppm)
4.0	3.0473	26.9527	89.84	2695.2700
6.0	0.3572	29.6428	98.81	2964.2800
9.0	ND	-	-	-
11.0	1.6887	28.3113	94.37	2831.1300
12.0	0.6603	29.3397	97.80	2933.9700

Table 3.7: Langmuir and Freundlich Adsorption isotherms of Pb<sup>2+</sup> on Acidified Bentonite Clay.

Q <sub>i</sub>	Q <sub>f</sub> (mg/L)	Q <sub>e</sub> (mg/g)	1/Q <sub>e</sub> (g/mg)	1/Q <sub>F</sub> (L/mg)	Log Q <sub>e</sub>	Log Q <sub>F</sub>
10.0	1.2995	17.4010	0.0575	0.7695	1.2406	0.1138
20.0	-	-	-	-	-	-
30.0	0.7685	58.4630	0.0171	1.3012	1.7669	0.1144
40.0	-	-	-	-	-	-
50.0	0.4103	99.1794	0.010	2.4372	1.9964	0.3869

Table 3.8: Adsorption Kinetic Model for Pb<sup>2+</sup> Adsorption on Acidified Bentonite Clay.

t (min)	Q <sub>f</sub> (mg/g)	Q <sub>t</sub> (mg/g)	Q <sub>e</sub> -Q <sub>t</sub>	Log (Q <sub>e</sub> -Q <sub>t</sub> )	t/Q <sub>t</sub> min (mg/g)	t <sup>1/2</sup> (min) <sup>1/2</sup>
10	0.0211	29.9789	0.0000	0.0000	0.3336	3.1623
20	-	-	-	-	-	-
30	0.9842	29.0158	0.9631	0.0177	1.0339	5.4772
40	1.2623	28.7377	1.2412	0.0934	1.3919	6.3246
50	-	-	-	-	-	-

Table 3.9: Thermodynamic of Adsorption of Pb<sup>2+</sup> on Acidified Bentonite Clay

T °K	1/T °K <sup>-1</sup>	Q <sub>f</sub>	Q <sub>e</sub>	K <sub>C</sub>	Log K <sub>C</sub>	Θ	(1-Θ)
303	0.0033	0.5052	29.4948	57.8242	1.7621	0.9794	0.0201
313	0.0032	0.1634	29.8366	182.5985	2.2615	5.1199	4.1199
323	0.0031	1.1448	28.8552	25.2055	1.4015	-0.1265	1.1265
333	0.0030	-	-	-	-	-	-
343	0.0029	0.0742	29.9258	403.3127	2.6056	12.4771	11.4771

Table 3.10: Adsorption Isotherm Constants for Pb<sup>2+</sup> Sorption on Acidified Bentonite Clay

Langmuir Isotherm	Freundlich Isotherm
Q <sub>max</sub> = 15.3846	1/n = 1.4880
K <sub>L</sub> = -2.6001	K <sub>f</sub> = 29.8538
-	n = 0.6720
R <sup>2</sup> = 0.689	R <sup>2</sup> = 0.5669

Table 3.11: Dimensionless Langmuir Separation Factor

Conc (mg/L)	10	20	30	40	50
R <sub>L</sub>	-0.04	-0.0196	-0.01299	-0.0001	-0.0078

Table 3.12: Kinetic Parameters for Adsorption of Pb<sup>2+</sup> onto Acidified Bentonite Clay.

Pseudo-first order	Pseudo-second order	Intra-particle diffusion
K <sub>ad</sub> = -0.0046	K <sub>2</sub> = -0.064	K <sub>d</sub> = -0.397
Q <sub>e</sub> , Cal = -0.0046	Q <sub>e</sub> , Cal = 28.5714	I = 31.22
R <sup>2</sup> = 0.423	R <sup>2</sup> = 1	R <sup>2</sup> = 0.997

Table 3.13: Thermodynamic Parameters for Adsorption of Pb<sup>2+</sup> onto Acidified Bentonite Clay

Temperature T(°K)	Gibbs Free Energy ΔG <sup>o</sup> (KJ/mol)
303	-10221.0023
313	-13593.2431
323	-8666.0239
333	-
343	17109.3913

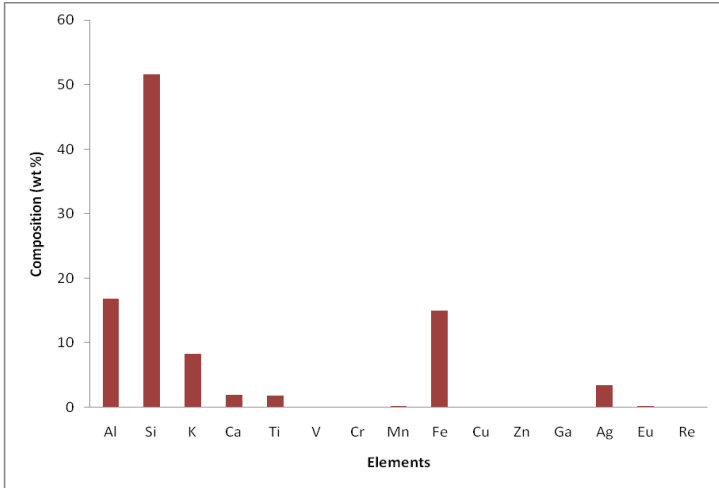


Figure 1: Elemental composition of Acidified Bentonite Clay.

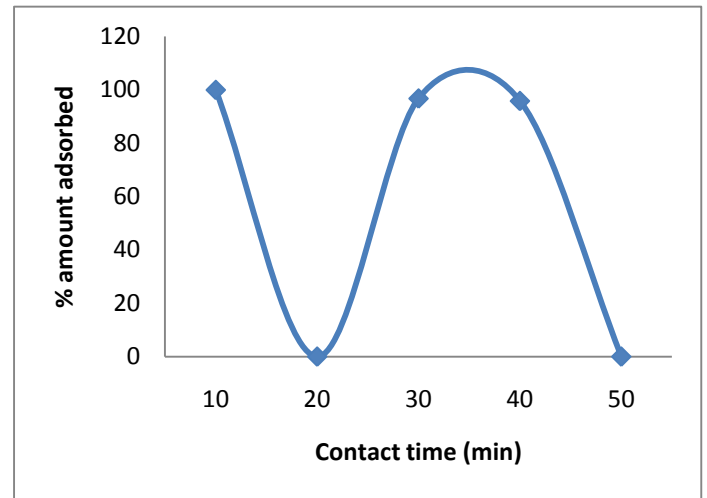


Figure 4: Effect of contact time on amount adsorbed

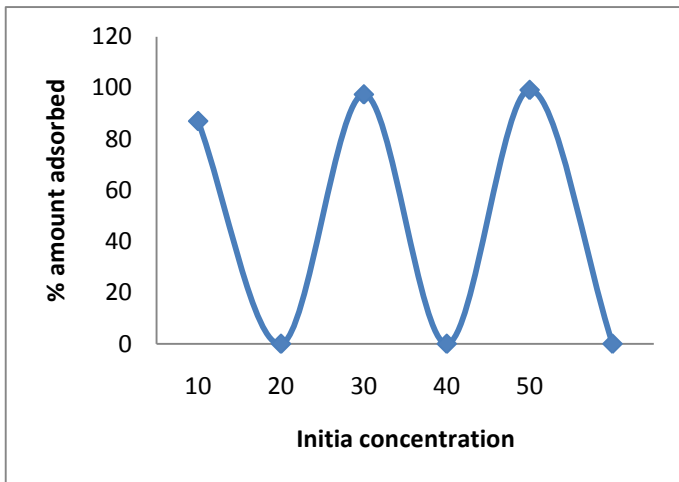


Figure 2: Effect of initial ion concentration on amount adsorbed

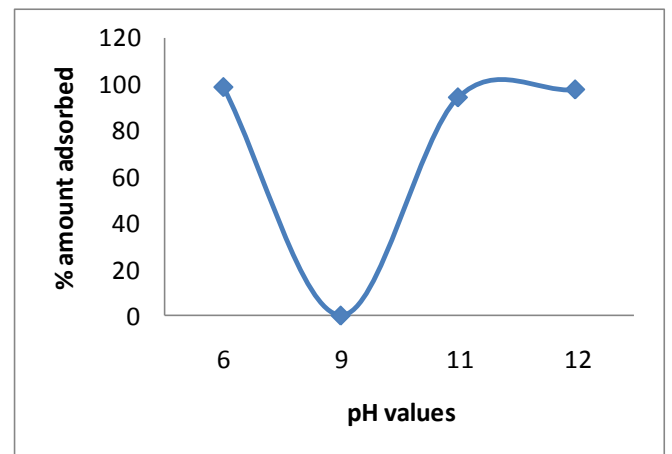


Figure 5: Effect pH on amount adsorbed

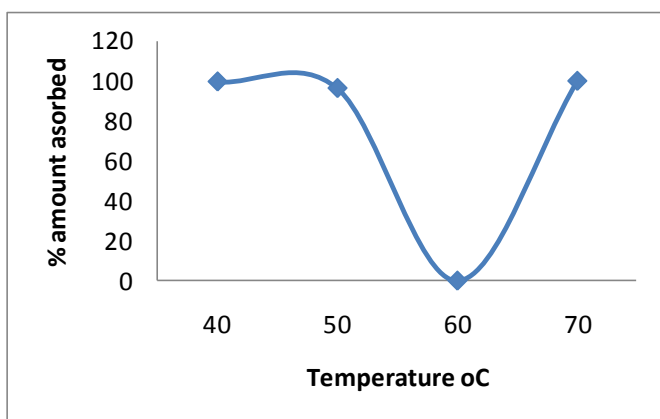


Figure 3: Effect of temperature on amount adsorbed

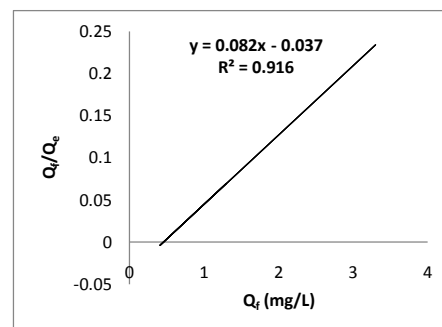


Figure 6: Langmuir Isotherm for Adsorption of Pb(II) on Acidified Bentonite Clay

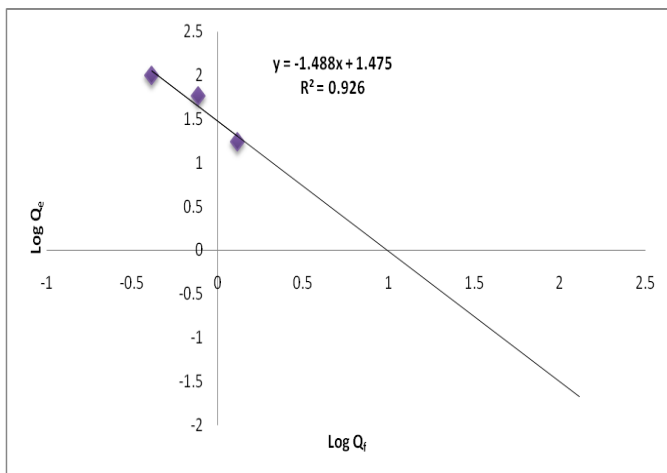


Figure 7: Freundlich Isotherm for the Adsorption of Pb(II) ion on Acidified Bentonite Clay

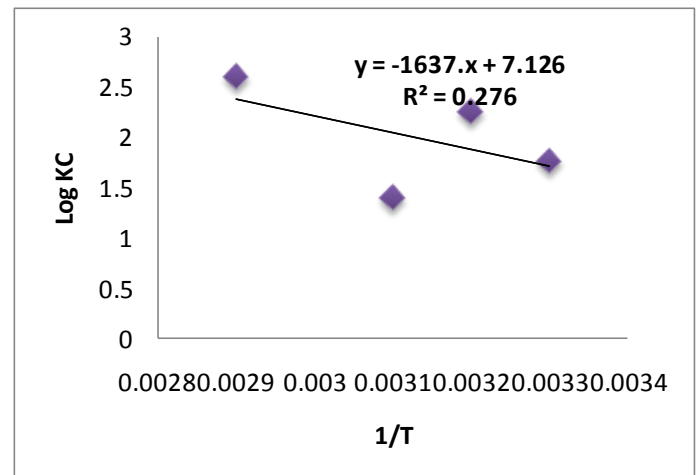


Figure 10: LogK<sub>c</sub> versus 1/T for Adsorption of Pb(II) ion onto Acidified Bentonite Clay

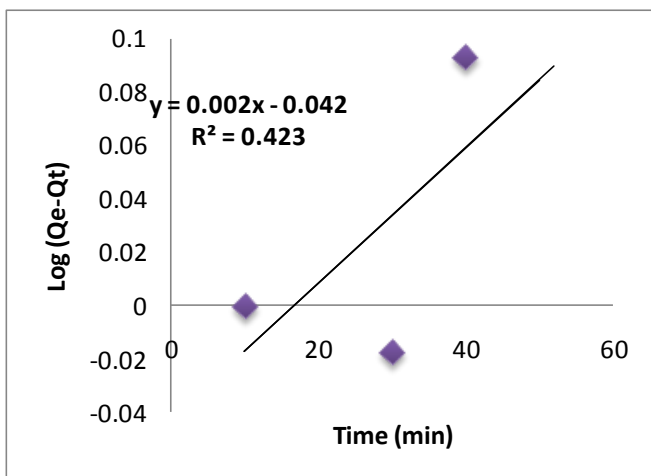


Figure 8: First Order Kinetic for Adsorption of Pb(II) Ion on Acidified Bentonite Clay

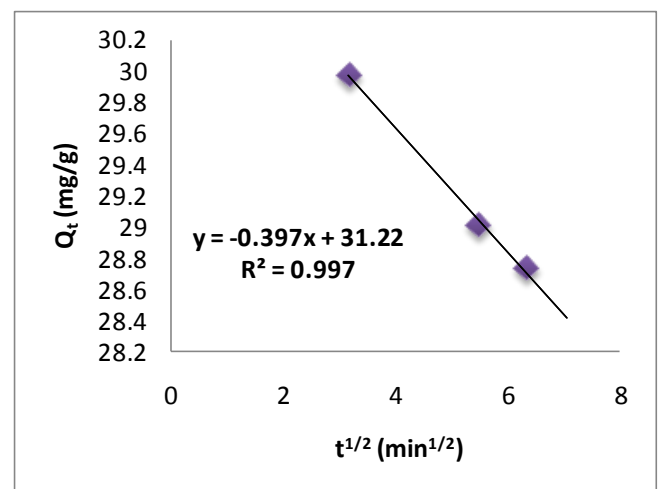


Figure 11: Intra-Particle Diffusion for Adsorption of Lead ion onto Acidified Bentonite Clay

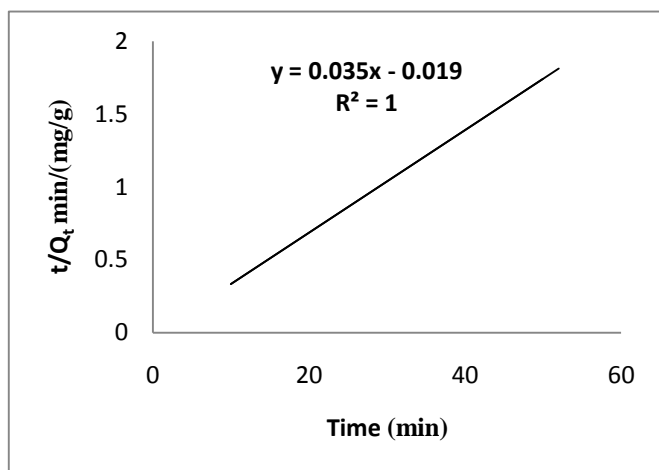


Figure 9: Second Order Kinetic for Adsorption of Pb(II) Ion by Acidified Bentonite Clay

#### IV. DISCUSSION

##### A. CHEMICAL ANALYSIS OF ACIDIFIED BENTONITE CLAY

Chemical analysis was carried out on acidified bentonite clay using X-Ray Fluorescence Spectrometer (XRF) to determine the chemical composition of the clay. The result of chemical analysis of acidified bentonite sample shows that, it is composed of Al (15.50%), Si (50.60%), K (8.82%), Ca (1.79%), Ti (1.89%), V (0.08%), Cr (7.08%), Mn (0.17%), Fe (13.42%), Cu (0.03%), Zn (0.04%), Ga (0.04%), Au (0.17%), Eu (0.26%), and Re (0.10%), as shown in Table 1 and Figure 1. The composition of the clay composed of Si, and Al as major elements, Fe, K, Cr, Ti, and Ag in moderate amount, V, Cr, Mn, Cu, Zn, Ga, Eu, and Re in trace quantity. This result is in agreement with the literature value which ascertained that clay is majorly composed of silicate and alumina and other elements like Fe, Ca, K, Cr, Mn, Cu, Zn, Ga, Au, Eu, and Re as impurities.



### **B. BET Analysis**

BET analysis was carried out on acidified- bentonite clay to determine the surface area since the rate of adsorption depends on the surface area of the adsorbent. The result of the analysis is shown in Table 2. The result shows that the micro pore volume is 1.746 (cm<sup>3</sup>), and micro pore area is 1424.3 (m<sup>2</sup>/g). Generally clay is associated with a small fraction of the pore volume and is similar to the result obtained from this investigation. The use of a modified BET equation permits a more realistic estimate of the monolayer capacity than that one obtained using the  $n=\infty$ . The value of micro-pore volume and micro-pore area shows that the clay could lead to better sorption capacity.

### **C. Effects of initial metal ion concentration**

The effect of metal ion concentration in the adsorption of lead ions by acidified bentonite clay is illustrated in Table 3.3 and Figure 2. It can be ascertained that the adsorption capacity of acidified bentonite clay for lead ion increased with increasing initial metal ion concentration from 10ppm to 50ppm. At the concentration of 10.0ppm, 87.01% of lead ion was adsorbed and no amount of lead ion was detected at 20 ppm. This could be due to unavailability of active site of the adsorbent. At the initial concentration of 30ppm, 97.44% adsorption was recorded and no amount was observed at 40ppm. Maximum adsorption of 99.18% was recorded at initial concentration of 50ppm as shown in Figure 2. This regular increase in efficiency of the bentonitic clay could be due to the availability of the unoccupied surface area of the bentonite since adsorption depends on the surface area of the adsorbent (Qadeer and Akhtar, 2005).

### **D. Effect of Temperature on Adsorption.**

The effect of temperature on the removal of Pb<sup>2+</sup> is shown in Table 3. 4. The result shows that the adsorption capacity of acidified-bentonite clay increase with increasing temperature from 30°C to 40°C and later decreases from 40°C to 50°C and again increased at 70°C, 98.32% of Pb<sup>2+</sup> was adsorbed at the temperature of 30°C. At 40°C, 50°C the amount adsorbed were 99.46%, 96.18% of respectively and no amount of percentage adsorption was detected at the temperature of 60°C, this could be due to complete occupied active sites. At 70°C, the amount adsorbed was 99.75% which indicate the maximum adsorption. From the result in Figure 3 and Table 3.4, it shows that the rate of adsorption depends on the temperature, though the fluctuation in the percentage adsorbed may be due to experimental error.

### **E. Effect of Contact Time on Adsorption**

The rate of adsorption is an important parameter in the treatment of industrial wastewater. The time-dependent behavior of Pb<sup>2+</sup> was measured by varying the equilibrium time between the adsorbate and adsorbent in the range of 10– 50 min, constant initial concentration of 30ppm and 0.5g were maintained throughout the experiment. The effect of contact time on the removal of Pb<sup>2+</sup> is presented in Table 3.5, and Figure 4. It can be seen that the rate of adsorption of Pb<sup>2+</sup> decreases with increasing contact time. At the contact time of 10min, 99.93% was adsorbed which shows that maximum adsorption was reached very quickly, indicating that the adsorption sites were well exposed for adsorption to take place. The percentage amount adsorbed was not detected at 20min. this may be due to insufficient active sites for more adsorption to take place or due to experimental error. At 30min, 40min, the amount adsorbed were 96.72% and 95.79% respectively and no amount of

adsorption was detected at 50 min. This result shows that maximum adsorption was reach very quickly at the initial contact time, further increase in contact time lead to decrease in adsorption. This could be as a result of the force of repulsion between the adsorbate and adsorbent molecules on the bentonite surface in the bulk phase.

### **F. Effect of pH on the Adsorption**

The pH of the aqueous solution is an important variable governing metal adsorption. Hence, it is obvious that this is partly due to the fact that the competition between hydrogen ions and the solution of pH affect the chemical composition as well as the ionization of the functional groups onto the adsorbent surface (Kadirvely and Namasivayam, 2003). The effect of pH on the adsorption of Pb<sup>2+</sup> onto the bentonite was investigated as shown in Table 3.6, and Figure 5. The uptake of Pb<sup>2+</sup> increases with increasing pH from 4.0 to 6.0. The increase in metal removal as pH increases can be explained on the basis of decrease in competition between the hydronium ions and the lead species for the surface sites and also by decrease in positive surface charge on the adsorbent which lower the electrostatic force of repulsion between the surface of the bentonite and the metal ion. Hence, adsorption of Pb<sup>2+</sup> increases (Pat nukao et al, 2008). At the pH of 4.0, 6.0 the amount adsorbed were 89.84% and 98.81% respectively and no amount of Pb<sup>2+</sup> was adsorbed at pH of 9.0 which could be due to insufficient or unavailability of active site. At the pH of 11.0, 94.37% of lead was adsorbed and finally 97.10% was adsorbed at the pH of 12.0 this variation in the rate of adsorption is in agreement with the result of Ulmanu et al (2003).

### **B. Adsorption Isotherm Modeling**

The linear form of Langmuir and Freundlich isotherm for the adsorption of Pb<sup>2+</sup> onto acidified bentonite clay is shown in Figure 6 and Figure 7. The Langmuir and the Freundlich constants were determined using correlation coefficient (Table 3.7). A moderate regression correlation coefficient <1.0 were found in the studied isotherms. According to these results, the Langmuir and the Freundlich models are suitable for the description of adsorption of Pb<sup>2+</sup> by acidified bentonite at equilibrium in the studied concentration range. The sorption isotherm is characterized by certain constants, in which the values are expressed as the surface properties and affinity of the adsorbent can also be used to find the adsorption capacity of the clay. The magnitude of K<sub>f</sub> and 1/n values was found as 29.85 and 1.488 respectively. It also indicates that the value of 1/n is less than 1 which shows that adsorption of Pb<sup>2+</sup> by the bentonite clay is a favorable adsorption mechanism and form a relatively strong bond between the adsorbate and the adsorbent (Egila et al., 2010). The value of Q<sub>max</sub> and K<sub>L</sub> were also obtained from Langmuir plot in Figure 6 and the result shown in Table 3.7. The maximum adsorption capacity Q<sub>max</sub> determined from the Langmuir isotherm defined the total capacity of the adsorbent (15.3846 mg/g). The negative value of K<sub>L</sub> (-2.60) implies a weak positive bonding relationship of Pb<sup>2+</sup> to the clay. The separation factor values for all initial concentration Table 3.11. Were found to be less than 1, indicates a favorable sorption of Pb<sup>2+</sup> onto the clay (Asiagwu, 2012).

### **C. Thermodynamic Treatment of the Sorption Process**

The thermodynamic treatment of the sorption data shows that change Gibbs free energy  $\Delta G^{\circ}$  values were negative at all



temperature (Table 3.13). The negative values indicate the spontaneous nature of adsorption of metal ions by acid bentonite clay.

## V. CONCLUSION

The investigation shows that acidified bentonite clay is an effective adsorbent for the removal of  $Pb^{2+}$  from aqueous solutions. The result of lead ions adsorption by the bentonitic clay indicates that it is a good alternative adsorbent for the removal of lead from aqueous solution. Parameters such as initial ion concentration, pH, contact time and temperature on the adsorption of metal ion by the clay in batch experiment were examined and proven to be important parameters in describing adsorption capacity that characterized bentonite clay. Experimental results are in good agreement with Langmuir, and Freundlich isotherm models, and have shown a good fitting to the experimental data. The parameters obtained shows that acidified bentonite clay could be a cheap adsorbent substitute for adsorption and has a high tendency to be used as effective and economical adsorbent for heavy metal removal. Adsorption of  $Pb^{2+}$  obeys pseudo-second order equation with good correlation.

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