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## Evaluation Of Effects Of Selected Factors On Adsorption Kinetics Of Lead Ion Removal From Aqueous Solutions

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### A B S T R A C T

**Keywords:** *This paper presents a report on the removal of lead ions ( $Pb^{2+}$ ) from aqueous solutions through adsorption techniques using powdered corncobs. Corncobs were collected from Obafemi Awolowo University agricultural farm. The corncobs were washed with distilled water to remove impurities. The corncobs were dried at room temperature, pulverized, sieved into different particle sizes using standard sieve sizes and stored. Powdered corncobs (PCCS) were separated based on the size. Its micrograph structure, physical and chemical properties were determined using Microsoft Excel Solver, Analysis of Variance, Mass of Adsorbents, Significant Factors*

*The study shown that moisture content of the PCCS was 7.29 %, volatile solid at 550°C and 1200°C were 96.88 % and 99.44 % respectively. It was also revealed that mass of adsorbent, pH, particle size of the adsorbent, initial concentration of  $Pb^{2+}$  and adsorption time were significant factors that had effects on adsorption of  $Pb^{2+}$  onto PCCS at 95 % confidence level. It was concluded that lead ion can be removed by PCCS, the mass of the adsorbent had significant effects on adsorption kinetics.*

### 1. Introduction

Adequate removal of lead ions ( $Pb^{2+}$ ) from wastewaters originated from industrial, agricultural and mining is a major global problem. Lead find its way into receiving water bodies through these industrial activities. The persistent of the lead in the potable are very toxic to man, plant and animals. It is well known that  $Pb^{2+}$  accumulation in the human body causes a defect in human organs such as kidney and liver (Onipede *et al.*, 2015). It also affects the human central nervous system and anemia. It contributes to high blood pressure, depression and reduced intelligence quotient in children (Khan and Singh, 2010, Oshobamiro and Adewuyi, 2012, Onipede *et al.*, 2015, Oke *et al.*,

2016).  $Pb^{2+}$  removal from water and wastewaters are achieved using some of the following water and wastewater treatment techniques. The techniques are electrochemical processes (Olarinoye *et al.*, 2012, Oke *et al.*, 2016), chemical precipitation (Asubiojo and Ajelabi, 2009), filtration (Onipede *et al.*, 2015), ion exchange, reverse osmosis, coagulation, flocculation and adsorption (Onipede *et al.*, 2015). The disadvantages of some of these methods are the high cost of operation and the initial cost of chemical treatment. These disadvantages make the techniques not suitable in developing countries like Nigeria. It has been well documented that out of the all these water and wastewater treatment adsorption has been the cheapest, fastest and most effective technique for water purification and remediation of wastewater (Amoko *et al.*, 2015).

Some materials have been used for adsorption in wastewater remediation. The materials used include peat; sugar cane bagasse, maize tassel, brick (Allahdin *et al.*, 2014), clay (Kede *et al.*, 2014), alumina (Ismael and Edpye 2014), bark (Choudhry *et al.*, 2014) zeolite tuff (Smical *et al.*, 2010), walnut shell (Almasi *et al.*, 2014), pineapple peel (Agarry and Aremu 2012), wheat bran, corn cob and human hair (Asubiojo and Ajelabi, 2009), coconut husk, bean chaffs (Oshobamiro and Adewuyi, 2012), coal, kaolinite, illite (Ajouyed *et al.*, 2011), egg shell (Oke *et al.*, 2008) and activated carbon (Zamora- Villafranes *et al.*, 2014). Oke *et al.* (2015) stated that Ho (2007) reviewed about 9058 articles had been published on adsorption of materials and Erhan *et al.* (2004) listed 37 carbon materials as low-cost adsorbents that had been considered. Additional information on adsorption can be established in literature such as Olarinoye *et al.* (2012), Onipede *et al.* (2015). It can be summarized that common adsorbent materials for adsorption of pollutants from aqueous solutions are activated carbon, synthetic resins, activated alumina agricultural solid wastes and natural adsorbents. Although, there are documents on adsorption of lead ion using various materials, literature on impacts of operational factors such as particle size of the adsorbent, initial pH of the solution, adsorbent mass and initial concentration of the pollutant are rare. The main target of the study was to test the effectiveness of agricultural solid waste (powdered corn cob) towards adsorption of  $Pb^{2+}$  wastewaters with particular attention to its adsorption kinetics and statistical evaluation of effects of selected factors.

## 2. Materials and Methods

Corncoobs were collected from an agricultural farm in Obafemi Awolowo University, Ile-Ife, Nigeria. The corncoobs were washed with distilled water to remove impurities. The corncoobs were dried at room temperature, ground into powder, sieved and classified using British Standard sieve. Powdered corncoobs (PCCS) was selected based on its availability and its lower initial cost of production. Powdered corncob with sieve sizes of 300 m, 212 m, 150 m and 75 m were separated and stored in different desiccators. The mineral contents of the PCCS were determined by using spectrophotometer (Jenway 7315) method after acid ( $HNO_3$ ) digestion of the samples (APHA, 2012; Mark *et al.*, 2016). Selected properties (physical and chemical) of the PCCS were determined using standard methods.

### 2.1 Moisture Content Determination

A well and adequate mixed 10.0 gram of the PCCS was dried in an initial weighed dish at  $105^\circ C$  to a constant weight in an oven (APHA, 2012, Fehintola *et al.*, 2015) and the moisture content ( $M_c$ ) of PCCS was computed as follows:

$$M_c (\%) = 100 \left( \frac{W_1 - W_2}{W_1} \right) \quad (1)$$

Where:  $M_c$  is the moisture contents,  $W_1$  and  $W_2$  are the initial and final weights of the PCCS after oven dried at  $105^\circ C$

Volatile and Ash Contents Determination: A known weight (5.0 gram) of the dried PCCS samples used (individually) for the determination of moisture content was placed in crucibles of known masses and transferred into a muffle furnace (Brother Furnace, XD 1220N). The muffle furnace was heated to  $550^\circ C$  and  $1200^\circ C$  for 2 hours. The PCCS samples were allowed to cool in desiccators to a room temperature and the final weights of the crucibles and PCCS were determined. Volatile solid ( $V_s$ ) and ash (Ash) contents of PCCS were computed as follows:

$$V_s (\%) = 100 \left( \frac{W_2 - W_3}{W_2} \right) \quad (2)$$

$$A_{sh} (\%) = 100 \left( \frac{W_4}{W_1} \right) \quad (3)$$

Where:  $W_3$  and  $W_4$  are the final weights of PCCS after 2 hours burnt in the muffle furnace at 550 and  $1200^\circ C$  respectively, Ash and  $V_s$  are the ash and volatile solid contents of the PCCS.

Water and Acid Solubilities Determination: Known dried masses (10.0 gram) of the PCCS were soaked in 300 ml of distilled water and 300 ml of 0.25 M of HCl individually for 24 hours for water and acid solubilities determination respectively. Each of the PCCS samples were filtered using pre-dried and weighed filter paper. Filtered PCCS samples and the filter papers were dried in the oven at  $105^\circ C$  for 24 hours separately and allowed to cool in desiccators to a room temperature. The final weights of the filtered PCCS were determined. The water ( $W_s$ ) and acid solubilities ( $A_s$ ) of the PCCS were computed as follows (Fehintola *et al.*, 2015):

$$W_s (\%) = 100 \left( \frac{W_2 - W_4}{W_2} \right) \quad (4)$$

$$A_s (\%) = 100 \left( \frac{W_2 - W_5}{W_2} \right) \quad (5)$$

Where:  $W_s$  is the water solubility of the PCCS,  $A_s$  is the acid solubility of the PCCS,  $W_d$  and  $W_s$  are the dry weight of the PCCS after soaked in the distilled water and the 0.25 M of HCl acid for 24 hours respectively.

## 2.2 Mineral Contents Determination:

A known mass (2.0 gram) of the PCCS was digested using trioxo-nitrate (V) acid digestion method as stated in Standard Methods for Water and Wastewater Analysis (APHA, 2012). The chemical properties of the PCCS were determined using standard methods (APHA, 2012) and the total metal concentrations ( $M_{cc}$ ) were determined using spectrophotometry method. Metal concentrations in the PCCS were computed as follows:

$$M_{cc} \text{ (mg / L)} = \left( \frac{A * B}{W_1} \right) \quad (6)$$

Where: B is the dilution factor, A is the concentration of the metals (mg/L) in the PCCS obtained from the reading and Mcc is the actual concentration of the metal.

Micrograph Structure and Adsorption Kinetics Determination: Micrograph structure of PCCS was conducted using Motic Microscope (Bi Advance series). Adsorption kinetics of the PCCS were determined using synthetic lead ion aqueous solutions (stock solutions) prepared using standard method (APHA, 2012; Marks et al., 2016). Working solutions of Pb<sup>2+</sup> were regularly prepared from the stock solution. In order to ascertain the adsorptions kinetics, known quantities of PCCS were added to 300ml of a solution containing 19.47 mg / L Pb<sup>2+</sup> solution, stirred for 3 minutes and allowed to settle. The supernatants from the treatment process were filtered through a filter paper at an interval of 1 hour, and the filtrates were analyzed for Pb<sup>2+</sup> concentration. For adsorptive rates of natural waters, raw water samples were collected from a selected surface water in Ile-Ife and subjected to a similar treatment as for the synthetic Pb<sup>2+</sup> solutions. The amount of solute removed (adsorbed) was computed using equation (7). The percentage of Pb<sup>2+</sup> removed (R%) from the solution was calculated using equation (8).

$$q_t = \left( \frac{(C_0 - C_t) V}{M} \right) \quad (7)$$

$$R(\%) = 100 \left( \frac{(C_0 - C_t)}{C_0} \right) \quad (8)$$

Where:  $q_t$  is the adsorption capacity of the PCCS at time t (mg/g),  $C_0$  is the initial concentration of lead in the solution (mg/l),  $C_t$  is the experimental concentration of lead ion in the solution at time t (mg/l), and  $R_t$  is the percentage of the lead ion

**Determination of Effect of Selected Factors:** Effects of pH on the removal of Pb<sup>2+</sup> from synthetic Pb<sup>2+</sup> solution was investigated using the PCCS of particle size 212 m (PCCS<sub>1</sub>) at different pH values (the pH of the solutions were controlled with either 0.01 Molarity HCl or 0.01 Molarity NaOH), at an initial lead concentration of 0.64 mg / L. The influence of the particle size of the adsorbent on the Pb<sup>2+</sup> removal from solution through adsorption processes was investigated using various particle sizes of the PCCS at pH 7.2 and at an initial Pb<sup>2+</sup> concentration of 0.64 mg / l. The effect of initial concentrations on the adsorptive rate of lead ion using batch adsorption experiments was investigated at initial concentrations between 0.13 mg / l and 19.47 mg / l at particle size 75 m (PCCS<sub>1</sub>) and pH 7.2. The laboratory analyses of pH and Pb<sup>2+</sup> concentrations in both synthetic and natural water used were conducted as specified in APHA (2012) using pH meter (Jenway 6051) and spectrophotometer (Jenway 7315) method for Pb<sup>2+</sup> concentrations. The adsorption kinetics of Pb<sup>2+</sup> adsorption onto PCCS was analyzed using a second-order pseudo, Elovich, and intra-particle diffusion kinetic models using Microsoft Excel Solver (Figure 1). Microsoft Excel Solver was used for the determination of the adsorption kinetics parameters based on availability at no additional cost. The second-order pseudo adsorption kinetic equation is expressed as shown in equation (9):

$$\left( \frac{t}{q_t} \right) = \frac{1}{h} + \frac{1}{q_e} t \quad (9)$$

Where:  $q_e$  is the equilibrium solid phase concentration of sorbate (mg/mg), t is the time,  $k_2$  is the rate constant of second-order pseudo adsorption. Assuming the  $h$  (mg/g · h) is equal to  $k_2(q_e)^2$  Erhan et al. (2004), Oke et al. (2008), Ismail et al. (2009) simplifies Elovich equation as follows:

$$q_t = \frac{1}{\beta} \log_e(\alpha\beta) + \frac{1}{\beta} \log_e(t) \quad (10)$$

Where:  $\beta$  is the desorption constant during any experiment and  $\alpha$  is the initial adsorption rate

The intraparticle diffusion model is based on the theory proposed by Weber and Morris (1963). It was tested to identify the diffusion mechanism. It is an empirical functional relationship and common to the most adsorption processes. The theory states that the uptake varies proportionally with  $t^{0.5}$  rather than with the contact time t. According to this theory the equation can be expressed as follows (Edson et al., 2011):

$$R = k_p (t)^{0.5} + C \quad (11a)$$

The other form of intraparticle diffusion model found in literature can be expressed as equation (11b) as follows:

$$R = k_{id}(t)^a \quad (11b)$$

Where: R is the percentage of the pollutant adsorbed (%), 'a' is the gradient of linear plots and  $k_{id}$  is the intraparticle diffusion rate const

Computation of Impacts of Selected Factors and Statistical Parameters: Impacts of the selected factors (pH, particle size, the initial concentration of  $Pb^{2+}$  and mass of the adsorbent) of adsorption kinetics models and model parameters were evaluated using analysis of variance (ANOVA), which are Sum of Square (SS), Mean Square (MS) and F-Value.

These selected statistical parameters were computed as follows (Oke et al., 2016):

$$SSA = (E_{HAs})^2 - \frac{T_e^2}{N} \quad (12)$$

Where: SSA is the sum of the square of factor A,  $T_e$  is the total effect of the factors,  $E_{HAs}$  is the effect of factor A and N is the total number of the sample.

$$MSA = \frac{SSA}{N-1} \quad (13)$$

Where: MSA is the mean square of the factor and N-1 is the degree of freedom of the factor.

$$F = \frac{MSA}{MSE} \quad (14)$$

Where: MSE is the mean square of the error and F is the F-value.

Applicability of the adsorption technique was conducted using raw water samples with various initial  $Pb^{2+}$  concentration. The procedure used for Microsoft Excel solver can be summarized as follows:

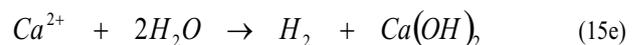
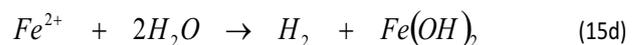
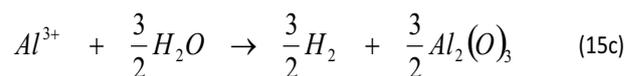
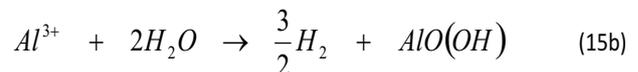
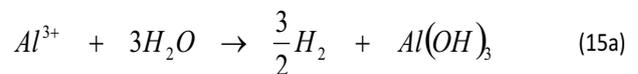
- Excel solver was added in the Microsoft Excel,
- Target, operation and changing cells were set, and
- Microsoft Excel Solver was allowed to iterate at 200 iterations with 0.005 tolerance (Figure1).

### 3. Results and Discussions

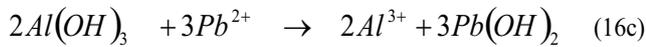
Results presentation and discussion of the study were done in the following ways: properties of the PCCS and equations of the PCCS with  $Pb^{2+}$ , ion exchange model, and statistical evaluation of the adsorption kinetics models and their parameters.

**Properties of Powdered Corn Cobs:** The study revealed that moisture content of the PCCS was 7.29 %, volatile solid at

550°C was 96.88 % ( 96.63 % based on the dried weight), and volatile solids at 1200°C was 99.44 % (99.44 % based on the dried weight). Ash contents of the PCCS were 3.13 % (3.37 % based on the dried weight), and 0.52 % (0.56 % based on the dried weight) at 550°C and 1200°C respectively. These results show that the PCCS contains organic matters and inorganic matters. Ogunjobi and Labunmi (2013) stated that yellow corncobs contained 9.80 % ash content and 3.81 % moisture, while white corn cobs had 9.77% ash and 6.43 % moisture contents. These results revealed that composition of corncobs is a function of the type of corncobs and locations. Results of water and acid solubilities were 4.53 % (2.54 % of dried weight) and 13.00 % (13.61 % of dried weight) respectively. Mineral composition of the PCCS indicated that one gram of PCCS contained 131.00 (13.10%) mg of Fe as  $Fe^{2+}$ , 1.70 mg calcium as  $Ca^{2+}$  (0.17%) and 0.010 mg Al as  $Al^{3+}$  (0.001%). Zinc and Nickel contents were 0.01 mg /g each with neither lead ion nor cadmium ion present. Okoronkwo *et al.* (2016) reported that corncobs ash contains 47.78 %  $SiO_2$ , 9.40 %  $Al_2O_3$ , 8.31 %  $Fe_2O_3$ , 16.70 %  $CaO$ , 7.80 %  $MgO$ , 2.70 %  $Mn_2O_3$ , 5.42 %  $K_2O$  and 1.89 %  $Na_2O$ . These results indicate that PCCS ash was made up alkali content ( $K_2O$  and  $Na_2O$ ) and silicates. It has been reported that some salts (calcium, iron and aluminum salts) undergo displacement reaction in aqueous as follows:



The first reaction (15a) forms the aluminum hydroxide bayerite ( $Al(OH)_3$ ) and hydrogen, the second reaction (15b) forms the aluminum hydroxide boehmite ( $AlO(OH)$ ) and hydrogen, and the third reaction (15c) forms aluminum oxide and hydrogen. All these reactions are thermodynamically favorable from room temperature past the melting point of aluminum (660°C). All are also highly exothermic. From room temperature to 280°C,  $Al(OH)_3$  is the most stable product, while from 280-480°C,  $AlO(OH)$  is most stable. Above 480 °C,  $Al_2O_3$  is the most stable product. This result shows that the PCCS underwent the reaction in equation (16) with arsenic ion, which can reduce the pH and the end product reacted with an arsenic ion to precipitate the pollutant as calcium, aluminium and iron salts.



These equations revealed that the PCCS underwent the reaction in equation (16) with  $Pb^{2+}$ , which reduced the pH of the treated solution and the end product reacted with  $Pb^{2+}$  to precipitate the pollutant. Figures 2a and 2b present the micrograph structures of the PCCS of various particle size.

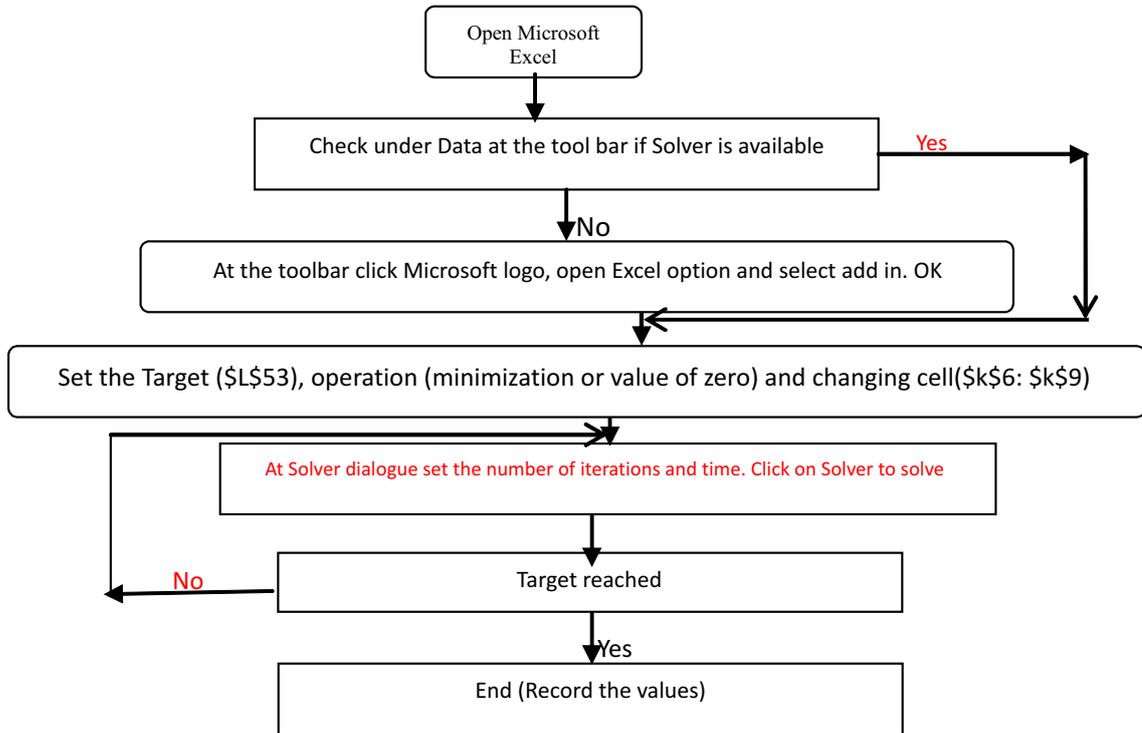


Figure 1: Procedure for using Microsoft Excel Solver in the computation of Adsorption Kinetics



Figure 2a: Micrograph of the PCCS of greater than 150  $\mu\text{m}$  sieve at 10000 magnification

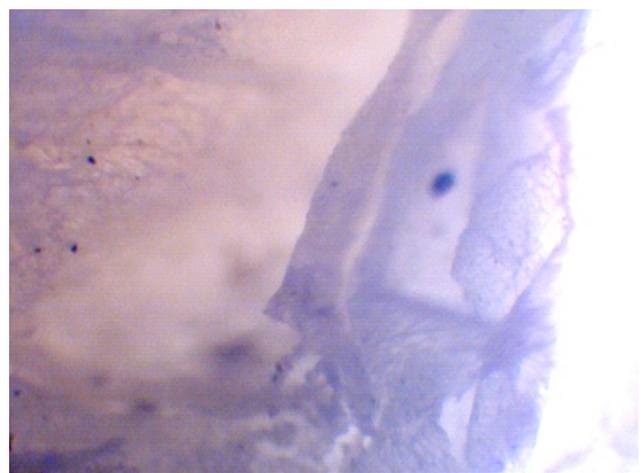


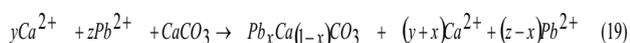
Figure 2b: Micrograph of the PCCS of less than 75  $\mu\text{m}$  sieve at 10000 magnification

Literature such as Wanitwattanarumlug *et al.*(2012), Amoko *et al.*(2015) shows effects of selected factors and reagents on micrograph structure of the PCCS. These figures (2a and 2b) and figures from literature revealed that the potassium hydroxide pre-treatment with microwave on corncobs was an effective technique for improving enzymatic hydrolysis accessibility. The optimum conditions for PCCS were found to be 2 % of KOH at 120 °C for a duration of 25 minutes which could increase in surface area by 45.67% and the cellulose crystallinity index of the material up to 57.28 %.

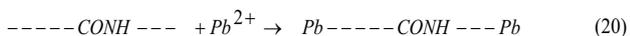
**Ion Exchange Model:** PCCS contains 96.88 % (96.63 %) volatile solids and 3.13 % (3.37 %) of ash content, which indicates that PCCS are organic and cellulose-based adsorbents. It is well known that organic compounds have polar functional groups that are utilized in chemical bonding. These groups are responsible for the cation exchange capacity of the PCCS. Thus, the PCCS and Pb<sup>2+</sup> reactions can be represented as follows:



Where: PCCSc<sup>-</sup> and HPCCSc<sup>-</sup> are the polar sites on the PCCS surface, and X is the pollutant Kohler *et al.*(2007) reported that removal of heavy metals such as lead, nickel cadmium in the presence of CaCO<sub>3</sub> can be represented as follows:



It was discovered that PCCS is a different organic substance with various organic functional groups, which provide the potential for bio-sorption of metal species. Reactions between the functional groups and the pollutants can be expressed as follows:



From these equations, it can be explicated that higher values of hydrogen concentration will lower the formation of XPCCSc<sub>2</sub>. This equation indicates that increasing pH value will not favour X<sup>2+</sup> adsorption. Also, decreasing the pH either through the addition of hydroxyl ions (OH<sup>-</sup>) or otherwise will increase adsorption of X<sup>2+</sup>. This reaction can be attributed to more charges, disassociation of more anions which will attract X<sup>2+</sup>, higher attraction forces and formation of lead hydroxyl ion (like X(OH)<sub>2</sub>) which will be precipitated or fill the pores. These observations from this study agree with Fehintola *et al.* (2015) observation and findings on adsorption of palladium and platinum onto solid waste from agricultural processes and ultra- structure of materials studied as documented by Amoko *et al.* (2015). More information on morphology properties of PCCS and other agricultural solid wastes are presented in Amoko *et al.* (2015) and Fehintola *et al.*

(2015).

Statistical Evaluation of Effects of Selected Factors on the Kinetics Models and their Parameters: Tables 1 to 4 present effect of the selected factors on the adsorption kinetics of Pb<sup>2+</sup> onto PCCS. From the tables, it is clear that mass of adsorbent (F2, 6 = 38.100, p = 0.0004), pH (F3, 6 = 26.949, p = 0.00001), particle size of the adsorbent (F3, 6 = 10.262, p = 0.0029), initial concentration of Pb<sup>2+</sup> (F3, 6 = 32.460, p = 4.867 x 10<sup>-6</sup>) and treatment period (adsorption time) (F3, 4 = 9.696, p = 0.0102) were significant factors that had effects on adsorption of Pb<sup>2+</sup> onto PCCS. These observations can be attributed to an increase in the pore and surface areas (with an increase in the mass of adsorbent and lower particle sizes of PCCS), availability of more pollutants to be removed (at higher initial concentration of Pb<sup>2+</sup>), adsorption and precipitation due to variation in the pH value and settlement due to higher adsorption period. Table 5 presents the response of Pb<sup>2+</sup> removal by adsorption in respect to raw water. Result from table 5 revealed that adsorption from the raw water samples were not significantly different (F3, 6 = 2.839, p = 0.0827) and time (F3, 4 = 265.904, p = 1.337 x 10<sup>-31</sup>) was a significant factor in the adsorption Pb<sup>2+</sup> from raw water. Tables 6 to 45 show effects of these selected factors on parameters of adsorption kinetics models (second-order pseudo, Elovich, and intra-particle diffusion). Tables 6, 8, 10 and 12 present effect of mass of adsorbent (F1, 4 = 16.63499, p = 0.01516), pH (F1, 6 = 0.0005, p = 0.983), particle size of the adsorbent (F1, 6 = 3.825, p = 0.098), initial concentration of Pb<sup>2+</sup> (F1, 6 = 0.219, p = 0.656) on second-order pseudo adsorption kinetics. Tables 7, 9, 11 and 13 present effect of mass of adsorbent (F1, 4 = 8.0345, p = 0.047), pH (F1, 6 = 11.797, p = 0.014), particle size of the adsorbent (F1, 6 = 12.902, p = 0.011), initial concentration of Pb<sup>2+</sup> (F1, 6 = 0.096, p = 0.768) on second-order pseudo constant (k<sub>2</sub>). These results shown that mass of adsorbent, pH, particle size of the adsorbent and initial concentration of Pb<sup>2+</sup> had effects on second-order pseudo adsorption kinetics and their parameters, but the effects were not significant for adsorption equilibrium at 95 % confidence level. In respect of k<sub>2</sub>, these factors (mass of adsorbent, pH, particle size of the adsorbent and initial concentration of Pb<sup>2+</sup>) had significant effect at 95 % confidence level. Tables 14 and 15 revealed that raw water had significant effects on second-order pseudo adsorption kinetics and its parameter (k<sub>2</sub>) at 95 % confidence level (F1, 6 = 55.8614, p = 0.0003) and (F1, 6 = 12.707, p = 0.012) respectively. Tables 16, 18, 20 and 22 present effect of mass of adsorbent (F1, 4 = 24.874, p = 0.008), pH (F1, 6 = 2.820, p = 0.144), particle size of the adsorbent (F1, 6 = 227.648, p = 5.34 x 10<sup>-6</sup>), initial concentration of Pb<sup>2+</sup> (F1, 6 = 1.600, p = 0.253) on Elovich constant alpha (α). Tables 17, 19, 21 and 23 present effect of mass of adsorbent (F1, 4 = 1.785, p =

0.253), pH (F1, 6 = 9.058, p = 0.024), particle size of the adsorbent (F1, 6 = 27.792, p = 0.002), initial concentration of Pb<sup>2+</sup> (F1, 6 = 1.600, p = 0.253) on Elovich constant ( $\alpha$ ). These results shown that pH and initial concentration of Pb<sup>2+</sup> had effects on Elovich adsorption kinetics and their parameters ( $\alpha$ ), but their effects were not significant for adsorption equilibrium at 95 % confidence level. The effect of mass of adsorbent, and particle size of the adsorbent on  $\alpha$  was significant at 95 % confidence level. In respect of, these factors (pH and particle size of the adsorbent) had significant effect at 95 % confidence level. Tables 24 and 25 revealed that raw water had significant effects on Elovich adsorption kinetics model and its parameters ( $\alpha$  and  $\beta$ ) at 95 % confidence level (F1, 6 = 21.84, p = 0.0034) and (F1, 6 = 293.034, p = 2.54 x 10<sup>-6</sup>) respectively.

Tables 26, 28, 30 and 32 present effect of mass of adsorbent (F1, 4 = 19.866, p = 0.011), pH (F1, 6 = 5.843, p = 0.052), particle size of the adsorbent (F1, 6 = 609.399, p = 2.91 x 10<sup>-7</sup>), initial concentration of Pb<sup>2+</sup> (F1, 6 = 2.100, p = 0.197) on constant k in intra-particle diffusion kinetics based Weber and Morris (1963) of R = kt<sup>0.5</sup> + C. Tables 27, 29, 31 and 33 present effect of mass of adsorbent (F1, 4 = 21.517, p = 0.010), pH (F1, 6 = 13.972, p = 0.010), particle size of the adsorbent (F1, 6 = 43.659, p = 0.001), initial concentration of Pb<sup>2+</sup>

(F1, 6 = 3.225, p = 0.123) on constant C in intra-particle diffusion kinetics based Weber and Morris (1963) of R = kt<sup>0.5</sup> + C. These results shown that mass of adsorbent, pH, initial concentration of Pb<sup>2+</sup> and particle size of the adsorbent had effects on intra-particle diffusion kinetics based Weber and Morris (1963) adsorption kinetics and their parameters, but the effects of initial concentration of Pb<sup>2+</sup> was not significant for adsorption intra-particle diffusion kinetics based Weber and Morris (1963) at 95 % confidence level. In respect of C, these factors (mass of adsorbent, pH and particle size of the adsorbent) had significant effect at 95 % confidence level. Tables 34 and 35 revealed that raw water had significant effects on intra-particle diffusion kinetics based Weber and Morris (1963) and its parameters (k and C) at 95 % confidence level (F1, 6 = 35.42583, p = 0.00101) and (F1, 6 = 226.721, p = 5.41 x 10<sup>-6</sup>) respectively.

Tables 36, 38, 40 and 42 present effect of mass of adsorbent (F1, 4 = 17.2759, p = 0.0142), pH (F1, 6 = 7.763, p = 0.032), particle size of the adsorbent (F1, 6 = 81.8865, p = 0.0001), initial concentration of Pb<sup>2+</sup> (F1, 6 = 2.384, p = 0.174) on constant k in intra-particle diffusion kinetics based on R = kidt<sup>n</sup>.

Table 1: Effect of adsorbent mass on adsorption of Pb<sup>2+</sup> onto PCCS

Source of Variation	Sum of Squares	Degree of freedom	Mean Square	F- Value	P-value
Effect of Mass of Adsorbent	0.238	2	0.119	38.100	0.0004
Effect of Adsorption Period	0.091	3	0.030	9.696	0.0102
Error	0.019	6	0.003		
Total	0.347	11			

Table 2: Effect of pH on adsorption of Pb<sup>2+</sup> onto PCCS

Source of Variation	Sum of Squares	Degree of freedom	Mean Square	F- Value	P-value
Effect of pH	1.561	3	0.520	26.949	0.00001
Effect of Time	1.059	4	0.265	13.706	0.00020
Error	0.232	12	0.019		
Total	2.852	19			

Table 3: Effect of PCCS particle size on adsorption of Pb<sup>2+</sup> onto PCCS

Source of Variation	Sum of Squares	Degree of freedom	Mean Square	F- Value	P-value
Effect of Particle size of PCCS	0.075	3	0.025	10.262	0.0029
Effect of Adsorption time	0.097	3	0.032	13.157	0.0012
Error	0.022	9	0.002		
Total	0.194	15			

Table 4: Effect of initial Pb<sup>2+</sup> concentration on adsorption of Pb<sup>2+</sup> onto PCCS

Source of Variation	Sum of Squares	Degree of freedom	Mean Square	F- Value	P-value
Effect of Initial Concentration of Lead	28421.151	3	9473.717	32.460	4.867 x 10 <sup>-6</sup>
Effect of Adsorption Time	2854.696	4	713.674	2.445	0.1033
Error	3502.263	12	291.855		
Total	34778.109	19			

Table 5: Effect of raw Water on adsorption of  $Pb^{2+}$  onto PCCS

Source of Variation	Sum of Squares	Degree of freedom	Mean Square	F- Value	P-value
Effect of The Raw Water Samples	30.465	3	10.155	2.839	0.0827
Effect of Adsorption Time	3804.649	4	951.162	265.904	$1.337 \times 10^{-11}$
Error	42.925	12	3.577		
Total	3878.040	19			

Table 7: Effect of adsorbent mass on second-order pseudo adsorption constant ( $k_2$ )

Source of Variation	Sum of Squares	Degree of freedom	Mean Square	F- Value	P-value
Between $k_2$	0.52247	1	0.52247	8.034878	0.047125
Within $k_2$	0.260101	4	0.065025		
Total	0.782571	5			

Table 9: Effect of pH on second-order pseudo adsorption constant ( $k_2$ )

Source of Variation	Sum of Squares	Degree of freedom	Mean Square	F- Value	P-value
Between $k_2$	88.166	1	88.166	11.797	0.014
Within $k_2$	44.842	6	7.474		
Total	133.009	7			

Table 11: Effect of PCCS particle size on second-order pseudo adsorption constant ( $k_2$ )

Source of Variation	Sum of Squares	Degree of freedom	Mean Square	F- Value	P-value
Between $k_2$	0.059	1.000	0.059	12.902	0.011
Within $k_2$	0.028	6.000	0.005		
Total	0.087	7.000			

Table 13: Effect of initial  $Pb^{2+}$  concentration on second-order pseudo adsorption constant ( $k_2$ )

Source of Variation	Sum of Squares	Degree of freedom	Mean Square	F- Value	P-value
Between $k_2$	7.940	1.000	7.940	0.096	0.768
Within $k_2$	498.074	6.000	83.012		
Total	506.014	7.000			

Table 6: Effect of adsorbent mass on second-order pseudo adsorption kinetics (SPAE)

Source of Variation	Sum of Squares	Degree of freedom	Mean Square	F- Value	P-value
Between SPAE	566.5188	1	566.5188	16.63499	0.015116
Within SPAE	136.2234	4	34.05586		
Total	702.7422	5			

Table 8: Effect of pH on second-order pseudo adsorption kinetics

Source of Variation	Sum of Squares	Degree of freedom	Mean Square	F- Value	P-value
Between SPAE	0.0093	1	0.0093	0.00050	0.983
Within SPAE	111.209	6	18.535		
Total	111.219	7			

Table 10: Effect of PCCS particle size on second-order pseudo adsorption kinetics

Source of Variation	Sum of Squares	Degree of freedom	Mean Square	F- Value	P-value
Between SPAE	1113.410	1.000	1113.410	3.825	0.098
Within SPAE	1746.449	6.000	291.075		
Total	2859.859	7.000			

Table 12: Effect of initial  $Pb^{2+}$  Concentration on second order pseudo adsorption kinetics

Source of Variation	Sum of Squares	Degree of freedom	Mean Square	F- Value	P-value
Between SPAE	14.617	1.000	14.617	0.219	0.656
Within SPAE	400.766	6.000	66.794		
Total	415.383	7.000			

Table 14: Effect of raw water on second-order pseudo adsorption kinetics

Source of Variation	Sum of Squares	Degree of freedom	Mean Square	F- Value	P-value
Between SPAE	0.0070	1.0000	0.0070	55.8614	0.0003
Within SPAE	0.0008	6.0000	0.0001		
Total	0.0078	7.0000			

Table 16: Effect of adsorbent mass on Elovich alpha

Source of Variation	Sum of Squares	Degree of freedom	Mean Square	F- Value	P-value
Between Elovich alpha	59.198	1.000	59.198	24.874	0.008
Within Elovich alpha	9.520	4.000	2.380		
Total	68.718	5.000			

Table 18: Effect of pH on Elovich alpha

Source of Variation	Sum of Squares	Degree of freedom	Mean Square	F- Value	P-value
Between Elovich alpha	22.274	1.000	22.274	2.820	0.144
Within Elovich alpha	47.389	6.000	7.898		
Total	69.663	7.000			

Table 20: Effect of PCCS par ticle size on Elovich alpha

Source of Variation	Sum of Squares	Degree of freedom	Mean Square	F- Value	P-value
Between Elovich alpha	36.828	1.000	36.828	227.648	$5.34 \times 10^{-06}$
Within Elovich alpha	0.971	6.000	0.162		
Total	37.799	7.000			

Table 22: Effect of initial Pb<sup>2+</sup> Concentration on Elovich alpha

Source of Variation	Sum of Squares	Degree of freedom	Mean Square	F- Value	P-value
Between Elovich alpha	79.431	1.000	79.431	1.600	0.253
Within Elovich alpha	297.938	6.000	49.656		
Total	377.369	7.000			

Table 24: Effect of raw water on Elovich alpha

Source of Variation	Sum of Squares	Degree of freedom	Mean Square	F- Value	P-value
Between Elovich alpha	0.0018	1.0000	0.0018	21.8400	0.0034
Within Elovich alpha	0.0005	6.0000	0.0001		
Total	0.0023	7.0000			

Table 17: Effect of adsorbent mass on Elovich beta

Source of Variation	Sum of Squares	Degree of freedom	Mean Square	F- Value	P-value
Between Elovich beta	0.129	1.000	0.129	1.785	0.253
Within Elovich beta	0.289	4.000	0.072		
Total	0.419	5.000			

Table 19: Effect of pH on Elovich beta

Source of Variation	Sum of Squares	Degree of freedom	Mean Square	F- Value	P-value
Between Elovich beta	68.179	1.000	68.179	9.068	0.024
Within Elovich beta	45.110	6.000	7.518		
Total	113.290	7.000			

Table 21: Effect of PCCS particle size on Elovich beta

Source of Variation	Sum of Squares	Degree of freedom	Mean Square	F- Value	P-value
Between Elovich beta	0.139	1.000	0.139	27.792	0.002
Within Elovich beta	0.030	6.000	0.005		
Total	0.169	7.000			

Table 23: Effect of initial Pb<sup>2+</sup> concentration on Elovich beta

Source of Variation	Sum of Squares	Degree of freedom	Mean Square	F- Value	P-value
Between Elovich beta	1424.20	1.00	1424.20	1.39	0.28
Within Elovich beta	6140.95	6.00	1023.49		
Total	7565.15	7.00			

Table 25: Effect of raw water on Elovich beta

Source of Variation	Sum of Squares	Degree of freedom	Mean Square	F- Value	P-value
Between Elovich beta	2891.734	1.000	2891.734	293.034	$2.54 \times 10^{-6}$
Within Elovich beta	59.210	6.000	9.868		
Total	2950.943	7.000			

Table 26: Effect of adsorbent mass on Weber and Morris (1963) constant (k)

Source of Variation	Sum of Squares	Degree of freedom	Mean Square	F- Value	P-value
Between k	24.767	1.000	24.767	19.866	0.011
Within k	4.987	4.000	1.247		
Total	29.754	5.000			

Table 28: Effect of pH on Weber and Morris (1963) constant (k)

Source of Variation	Sum of Squares	Degree of freedom	Mean Square	F- Value	P-value
Between k	46.303	1.000	46.303	5.843	0.052
Within k	47.545	6.000	7.924		
Total	93.848	7.000			

Table 30: Effect of PCCS particle size on Weber and Morris (1963) constant (k)

Source of Variation	Sum of Squares	Degree of freedom	Mean Square	F- Value	P-value
Between k	17.546	1.000	17.546	609.399	$2.91 \times 10^{-7}$
Within k	0.173	6.000	0.029		
Total	17.719	7.000			

Table 32: Effect of initial Pb<sup>2+</sup> Concentration on Weber and Morris (1963) constant (k)

Source of Variation	Sum of Squares	Degree of freedom	Mean Square	F- Value	P-value
Between k	99.582	1.000	99.582	2.100	0.197
Within k	284.459	6.000	47.410		
Total	384.041	7.000			

Table 34: Effect of raw water on Weber and Morris (1963) constant (k)

Source of Variation	Sum of Squares	Degree of freedom	Mean Square	F- Value	P-value
Between k	0.00062	1.00000	0.00062	35.42583	0.00101
Within k	0.00011	6.00000	0.00002		
Total	0.00073	7.00000			

Table 27: Effect of adsorbent mass on Weber and Morris (1963) constant (C)

Source of Variation	Sum of Squares	Degree of freedom	Mean Square	F- Value	P-value
Between C	11.122	1.000	11.122	21.517	0.010
Within C	2.068	4.000	0.517		
Total	13.190	5.000			

Table 29: Effect of pH on Weber and Morris (1963) constant (C)

Source of Variation	Sum of Squares	Degree of freedom	Mean Square	F- Value	P-value
Between C	107.166	1.000	107.166	13.972	0.010
Within C	46.019	6.000	7.670		
Total	153.185	7.000			

Table 31: Effect of PCCS particle size on Weber and Morris (1963) constant (C)

Source of Variation	Sum of Squares	Degree of freedom	Mean Square	F- Value	P-value
Between C	5.869	1.000	5.869	43.659	0.001
Within C	0.807	6.000	0.134		
Total	6.675	7.000			

Table 33: Effect of initial Pb<sup>2+</sup> concentration on Weber and Morris (1963) constant (C)

Source of Variation	Sum of Squares	Degree of freedom	Mean Square	F- Value	P-value
Between C	150.146	1.000	150.146	3.225	0.123
Within C	279.323	6.000	46.554		
Total	429.469	7.000			

Table 35: Effect of raw water on Weber and Morris (1963) constant (C)

Source of Variation	Sum of Squares	Degree of freedom	Mean Square	F- Value	P-value
Between C	0.00717	1.00000	0.00717	226.72107	$5.41 \times 10^{-6}$
Within C	0.00019	6.00000	0.00003		
Total	0.00736	7.00000			

Table 36: Effect of adsorbent mass on Intra Particle model constant ( $k_{id}$ )

Source of Variation	Sum of Squares	Degree of freedom	Mean Square	F- Value	P-value
Between $k_{id}$	6.3916	1.0000	6.3916	17.2759	0.0142
Within $k_{id}$	1.4799	4.0000	0.3700		
Total	7.8714	5.0000			

Table 38: Effect of pH on Intra-particle model constant ( $k_{id}$ )

Source of Variation	Sum of Squares	Degree of freedom	Mean Square	F- Value	P-value
Between $k_{id}$	58.523	1.000	58.523	7.763	0.032
Within $k_{id}$	45.229	6.000	7.538		
Total	103.753	7.000			

Table 40: Effect of PCCS particle size on Intra Particle model constant ( $k_{id}$ )

Source of Variation	Sum of Squares	Degree of freedom	Mean Square	F- Value	P-value
Between $k_{id}$	4.5752	1.0000	4.5752	81.8865	0.0001
Within $k_{id}$	0.3352	6.0000	0.0559		
Total	4.9104	7.0000			

Table 42: Effect of initial  $Pb^{2+}$  Concentration on Intra Particle model constant ( $k_{id}$ )

Source of Variation	Sum of Squares	Degree of freedom	Mean Square	F- Value	P-value
Between $k_{id}$	111.870	1	111.870	2.384	0.174
Within $k_{id}$	281.559	6	46.927		
Total	393.429	7			

Table 44: Effect of raw water on Intra Particle model constant ( $k_{id}$ )

Source of Variation	Sum of Squares	Degree of freedom	Mean Square	F- Value	P-value
Between $k_{id}$	0.001021	1	0.001021	82.34719	0.0001
Within $k_{id}$	$7.44 \times 10^{-5}$	6	$1.24 \times 10^{-5}$		
Total	0.001095	7			

Table 37: Effect of adsorbent mass on intra-particle model constant (a)

Source of Variation	Sum of Squares	Degree of freedom	Mean Square	F- Value	P-value
Between 'a'	0.017	1.000	0.017	0.248	0.644
Within 'a'	0.271	4.000	0.068		
Total	0.288	5.000			

Table 39: Effect of pH on intra-particle model constant (a)

Source of Variation	Sum of Squares	Degree of freedom	Mean Square	F- Value	P-value
Between 'a'	73.616	1.000	73.616	9.847	0.020
Within 'a'	44.856	6.000	7.476		
Total	118.472	7.000			

Table 41: Effect of PCCS particle size on intra-particle model constant (a)

Source of Variation	Sum of Squares	Degree of freedom	Mean Square	F- Value	P-value
Between 'a'	0.6697	1.0000	0.6697	52.3643	0.0004
Within 'a'	0.0767	6.0000	0.0128		
Total	0.7465	7.0000			

Table 43: Effect of initial  $Pb^{2+}$  concentration on intra-particle model constant (a)

Source of Variation	Sum of Squares	Degree of freedom	Mean Square	F- Value	P-value
Between 'a'	116.874	1	116.874	2.517	0.164
Within 'a'	278.623	6	46.437		
Total	395.497	7			

Table 45: Effect of raw water on intra-particle model constant (a)

Source of Variation	Sum of Squares	Degree of freedom	Mean Square	F- Value	P-value
Between 'a'	0.494	1	0.494	181.608	$1.03 \times 10^{-5}$
Within 'a'	0.016	6	0.003		
Total	0.510	7			

Tables 37, 39, 41 and 43 present effect of mass of adsorbent ( $F_{1,4} = 0.248$ ,  $p = 0.644$ ), pH ( $F_{1,6} = 9.847$ ,  $p = 0.010$ ), particle size of the adsorbent ( $F_{1,6} = 52.3643$ ,  $p = 0.0004$ ), initial concentration of  $Pb^{2+}$  ( $F_{1,6} = 2.517$ ,  $p = 0.164$ ) on constant 'a' in intra-particle diffusion kinetics based on  $R = k_{id}t^a$ . These results shown that mass of adsorbent, pH, initial concentration of  $Pb^{2+}$  and particle size of the adsorbent had effects on intra-particle diffusion adsorption kinetics models and their parameters, but the effects of initial concentration of  $Pb^{2+}$  was not significant for adsorption intra-particle diffusion kinetics at 95 % confidence level. In respect of 'a', these factors (mass of adsorbent, pH and particle size of the adsorbent) had significant effect at 95 % confidence level. Tables 44 and 45 revealed that raw water had significant effects on intra-particle diffusion kinetics and its parameters (k and a) at 95 % confidence level ( $F_{1,6} = 82.34719$ ,  $p = 0.0001$ ) and ( $F_{1,6} = 181.608$ ,  $p = 1.03 \times 10^{-5}$ ) respectively.

## CONCLUSION

Based on the study the following conclusions can be drawn:

- lead ion can be removed by an inexpensive agricultural waste product – the powdered corn cob
- mass of adsorbent ( $F_{2,6} = 38.100$ ,  $p = 0.0004$ ), pH ( $F_{3,6} = 26.949$ ,  $p = 0.00001$ ), particle size of the adsorbent ( $F_{3,6} = 10.262$ ,  $p = 0.0029$ ), initial concentration of  $Pb^{2+}$  ( $F_{3,6} = 32.460$ ,  $p = 4.867 \times 10^{-6}$ ) and treatment period (adsorption time) ( $F_{3,4} = 9.696$ ,  $p = 0.0102$ ) were significant factors that influence lead ion adsorption onto the PCCS; and

## References

- Agarry, S.E. and Aremu, M.O. (2012). Batch equilibrium and kinetic studies of simultaneous adsorption and biodegradation of phenol by pineapple peels immobilized *Pseudomonas aeruginosa* NCIB 950. *British Biotechnology Journal* 2(1), 26-48
- Ajouyed, O., Hurel, C. and Marmier, N. (2011). Evaluation of the adsorption of hexavalent chromium on kaolinite and illite. *Journal of Environmental Protection* 2: 1347-1352
- Allahdin, O., Wartel, M., Mabingui, J. and Boughriet, A. (2014). Kinetic of divalent metals ( $Cd^{2+}$ ,  $Cu^{2+}$ ,  $Pb^{2+}$ ,  $Zn^{2+}$ ) adsorption onto a modified brick. *American Chemical Science Journal* 4(5): 687 – 705.
- Almasi, A., Omidi, M. Khodadadian, M., Khamutian, R. and Gholivard, M.B. (2012). Lead II and Cadmium II removal from aqueous solution using processed walnut shell, kinetic and equilibrium study. *Toxicological and Environmental Chemistry* 94(4): 660-671.
- Amoko, J. S., Obijole, O. A., Fehintola, E. O, Oke, I. A., Adeosun, O.O., Ojo, S. O., Bolorunduro, K. A., Foghi, P. U., Amele S. O., and Adegbite, A. A.(2015). Evaluation of Linear Regression Equations and Methods of Solving Linear Equations: Adsorption Kinetics Model Direct Research *Journal of Engineering and Information Technology* 3 (2), 7-30,
- APHA, (2012). Standard Method for the Examination of Water and Wastewater, 22th edn, America Water Works Association and Water Pollution Control Federation, Washington DC.
- Arellano, O., Flores, M., Guerra, J., Hidalgo, A., Rojas, D., and Strubinger, A., (2016), Hydrothermal carbonization (htc) of corncob and characterization of the obtained hydrochar, *Chemical Engineering Transactions*, 50, 235-240
- Asubiojo, O.J. and Ajelabi, O.B. (2009). Removal of heavy metals from industrial wastewater using natural adsorbents. *Toxicological*
- Choudhury, T. R., Amin, M. N., Quraishi, S. B. and Mustafa, A. I. (2014). Arsenic (III) removal from reallife groundwater by adsorption on Neem bark(*Azadirach indica* ). *International Research Journal of Pure and Applied Chemistry* 4(6), 594 – 604.
- Edson, L. F. , Gabriela, C. C. , Marcio, A. M. and Sérgio, L. J. (2011). Adsorption of Textile Dye on Zinc Stannate Oxide: Equilibrium, Kinetic and Thermodynamics Studies . *Separation Science and Technology*, 46: 2510–2516
- Erhan, D., Kobya, M., Elif, S., and Ozkan, T., (2004). Adsorption kinetics for the removal of chromium III from aqueous solutions on the activated carbonaceous prepared from agricultural wastes. *Water SA*, 30(4), 533-540.
- Fehintola, E. O.; Obijole , O. A.; Amoko, J. S. and Oke, I. A. (2015). Adsorption Equilibrium Isotherms Of Pb , Ni And Cd Ontopowdered Egg Shells. *Ife Journal of Science* 17 (1), 144 – 162
- Ho, Y.S (2007). Bibliometric Analysis of Adsorption Technology in Environmental Science. *Journal of Environmental Protection Science*, 1,1-11.
- Ismaeel, A. R. and Edpye, K. M. (2014). Effect of  $Cu^{2+}$  concentration on adsorption – sorptive mechanisms modes, critical concentration edge and spontaneity of octahedral ( $Cu(H_2O)_6^{2+}$ ) on  $\gamma$  Alumina. *American Chemical Science Journal* 4(2), 187 – 198
- Kede, C.M., Etoh, M.A., Ndigbewu, P.P., Ngomo, H.M. and Ghogomu, P.M. (2014). Equilibria and kinetic studies of the adsorption of cadmium onto Cameroonian wetland clays. *British Journal of Applied Science and Technology* 4(7), 1071-1088

- Khan, T.A. and Singh, V.V. (2010). Removal of cadmium (II) lead (II) and chromium (VI) ions from aqueous solution using clay. *Toxicological and Environmental Chemistry* 92(8): 1435–1446
- Marks, C. M. V., Per, H.N; Carlos, M. L. and Damir, B. (2016) *Experimental Methods in Wastewater Treatment*. 1<sup>st</sup> Edition, International Water Publishing Alliance House, London
- Ogunjobi J.K and Labunmi L. (2013) Characterisation of Bio-Oil and Bio-Char from Slow-Pyrolysed Nigerian Yellow and White Corn Cobs. *Journal of Sustainable Energy and Environment* 4, 77-84
- Oke, I. A. , Olarinoye, N.O. and Adewusi, S.R.A. (2008) Adsorption Kinetics for Arsenic Removal by Untreated Powdered Eggshell from Aqueous Solutions. *Journal of Adsorption Society*. 14,(1), 85-92
- Okoronkwo, E.A., Imoisili, P.E., Olubayode, S.A. and Olusunle, S.O.O. (2016) Development of Silica Nanoparticle from Corn Cob Ash. *Advances in Nanoparticles*, 5, 135-139
- Olarinoye, N. O. S. Lukman, J. A. Otun, D. B. Adie, Oke I. A., S. B. Igboro, Fasuyi- Enang O.T. and Ismail A.(2012). Multi-Component Adsorption Equilibria of  $2+$   $2+$  Pb and Cd onto Powdered Corn Cobs (PCC) in Water Treatment Processes, Editor: Kostas Demadis, First edition, Nova Science Publishers, Inc. New York
- Onipede, O. J., Oshodi, A. A. and Enahoro, P. O. (2015) Adsorption Equilibrium Study of Lead and Zinc on Rice Husk from Aqueous Solution. *Global Journal of Science Frontier Research: B Chemistry* 15, (1), 1 -11.
- Oshobamiro, M. T. and Adewuyi, G.O. (2012). Biosorption of  $Cd^{2+}$  and  $Pb^{2+}$  ions from wastewater using coconut husk and bean chaffs. *Continental Journal of Environmental Sciences* 6(3): 1–7.
- Smical, I., Mihaly – Cozmuta, L. and Costin, D. (2010). Research concerning the influence of several factors on  $Pb^{2+}$ ,  $Cu^{2+}$ , and  $Zn^{2+}$  ions adsorption by natural zeolite tuff from Maramure county northern Rumania. *Advances in Environmental Science International Journal of the Bioflux Society* 2(2): 171–180.
- Wanitwattanarumlug, B., Luengnaruemitchai, A and Wongkasemjit S (2012). Characterization of Corn Cobs from Microwave and Potassium Hydroxide Pretreatment. *International Journal of Chemical and Biological Engineering* 6:1-8.
- Weber, W.J. and Morris, J.C. (1963) Kinetic of adsorption on carbon from solution. *J. Sanit. Engin. Div., Am. Soc. Civil Eng.*, (89): 31.
- Zamora – Villafranes, E., Barcelo – Quintal, I.D., Gomez – Salazar, S., Barcelo – Quintal, M., Solis - Correa, H. E. and Soriano – Rodriguez, J. M. (2014). Adsorption kinetics of matter contained in leachates using eggshell and activated carbon. *Journal of Environmental Protection* 5, 608–619.