

Original Research Article

Kinetic Studies of Bio-sorption of Cyanide ions from Aqueous Solution using Shea Butter Seed Husk as Adsorbent

Abstract

This research work was conducted in order to investigate the adsorption of cyanide ions by carbon black developed from Shea Butter Seed Husk (SBSH) an eco-friendly bio-adsorbent. The experiments were carried out in batch reactors with optimum operating parameters at 100mg/l for the initial cyanide concentration, Temperature $30\pm 2^{\circ}\text{C}$, pH value 7, Adsorbent Dosage (3.0mg/100ml) and Contact Time of 90 minutes with maximum percentage cyanide ion removal at 94.56%. The values for the amount of cyanide ions adsorbed at equilibrium (q_e) and amount adsorbed at a given time (q_t) of the experimental results were fitted to the Langmuir, Halsey – Taylor (Freundlich), Henry and Slygin – Frumkin (Temkin) isotherm models with Henry Adsorption Isotherm having $R^2 = 0.966$, hence, best described the equilibrium model. Adsorption of cyanide ions by SBSH obeyed the Pseudo-Second Order Model rate equation with the values of $R^2 = 0.999$. $Q_e = 3.257$ and $k_2 = 0.093$. Therefore, it was observed that Pseudo-Second Order Model best represented the relationship for the maximum monolayer adsorption capacity of cyanide ions by SBSH.

Keywords: *Cyanide ions, Kinetics, Shea Butter Seed Husk, Adsorption, effluent treatment, Monolayer*

1. INTRODUCTION

The causes of most environmental challenges take their origins in the developmental process or in its failure and inadequacies (Gbehe, 2004), this is due to diverse anthropogenic activities such as agriculture, electroplating, metal finishing industries, metallurgical industries, tannery, fertilizer industries, pigments and dyes and manufacturing increases the level of heavy metal and cyanide ions in the environment (Reed *et al.*, 1994; Faisal and Hasnai, 2004). Basically, Waste water discharged by industrial activities is often contaminated by a variety of toxic or otherwise harmful substances which have negative effects on the water environment. For example, metal finishing industry and electroplating unit is one of the major sources of heavy metals and cyanide pollutants which contribute greatly to the pollution load of the receiving water bodies and therefore increase the environmental risk, cassava is also one of the staple food crops in Nigeria and can be processed in various ways, for instance, fermentation. Sometimes this is carried out in isolated locations such as use of pots or in flowing streams and rivers. This contributes to the cyanide load of the affected water bodies. Also decaying plants can contribute to the cyanide concentrations in natural waters.

Cyanide is a singly-charged anion containing unimolar amounts of carbon and nitrogen atoms triply-bounded together ($C \equiv N$). It is a strong ligand, capable of complexing at low concentrations with virtually any heavy metal. Because the discharge of industrial wastewater is becoming a serious environmental problem in Nigeria, cyanide and heavy metal ions are reported as prior pollutants due to their mobility in natural water ecosystem and their toxicity.(Nwabanne and Igbokwe; 2012). Thus cyanide ion goes to the environment and water body as effluents (industrial wastes).

Cyanide is included in the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) priority list of hazardous substances (ATSDR, CERCLA, 2007) and it occupies 28th

position in the list of most hazardous chemicals (ATSDR and USEPA, 2007). It is also listed among the 65 toxic pollutants in the Effluent Guideline and Standards given in title 40; section 400-475, of the Code of Federal Regulations (CFR, 2008).

Different forms of cyanide have awful health effects on people as well as other living organisms (Dursun *et al.*, 1999). Therefore the permissible limit of cyanide in the surface water according to Indian Standard (IS) has set a minimal national standard (MINAS) limit for cyanide ,in effluent as 0.2 mg/L (IS, 1974). USEPA (US Environmental Protection Agency) standard for drinking and aquatic-biota waters regarding total cyanide are 200 and 50 ppb respectively, (Young and Jordan, 2004). Therefore, environmental regulations require reducing the cyanide concentration in wastewater to below 0.2 mg/L prior to discharge into the environment. All forms of cyanide can be toxic at high levels, but the more toxic form of cyanide is hydrogen cyanide. Therefore, cyanide and metal cyanide complexes in industrial waste water must be treated or reduced to lowest levels before being discharged. Several treatment processes such as physical, chemical and biological oxidation have been exploited for the reduction of cyanide levels in waste solutions/ slurries in compliance with environmental regulations (Young and Jordan, 1995).

Both governmental and private sectors have now recognized the potential dangers that cyanide ion, heavy metal ions and other hydrocarbons (organic wastes) poses to human health and the environment at large. On response to address such environmental menace and outspread of diseases, many technological processes has been developed. Processes such as physical, chemical and biological oxidation methods have been exploited for the reduction of toxic ions and other contaminants during effluents and waste water treatment; in compliance with the environmental regulations such as the US Environmental Protection Agency (USEPA), Federal Environmental Protection Agency (FEPA), and Indian Minimal National Standard (IMINAS). Despite the availability of such skills to the treatment of contaminated sites, yet, the selection depends on the pollutants/contaminants and site characteristics, regulation requirements, costs and time constraints (Riser-Roberts, 1998; Reddy *et al.*, 1999).

Water pollution is generally induced by humans. It results from actions of humans carried on to better self. These could be treated under the various activities that man engages in.

Indiscriminate Human activities including industrialization and agricultural practices contributed immensely in no small measure to the degradation and pollution of the environment which adversely has an effect on the water bodies (rivers, streams, ponds and ocean) that has been a necessity for life.

The importance of water for sustenance of life cannot be overemphasized. Whether it is in use of running water in our homes, rearing cattle and growing crops in our farms, or the increased uses in industry, remain immeasurable. It has been the most important universal solvent therefore, to note that depletion of this commodity either through contamination, or careless use results in serious consequences.

Water pollution is the introduction of chemical, biological and physical matter into large bodies of water that degrade the quality of life that lives in it and consumes it. Water is polluted in many ways like effluent of leather and chemical industries, electroplating industries and dye industries (Ramya *et al.*, 2011). Several industrial and agricultural processes and mining activities have increased the concentration of toxic contamination in water and waste water around the world.

Water is considered polluted if some substances or condition is present to such a degree that the water cannot be used for a specific purpose. Olaniran (1995) defined water pollution to be the presence of excessive amounts of a hazard (pollutants) in water in such a way that it is no longer suitable for drinking, bathing, cooking or other uses. Pollution is the introduction of a contamination into the environment (Webster.com, 2010). It is created by industrial and commercial waster, agricultural practices, everyday human activities and most notably, models of transportation. No matter where you go and what you do, there are remnants earths environmental and its inhabitants in many ways.

Water pollution in Nigeria according to Gbamanja (1998) arises from various activities, among which are: Sewage leakages, High population density, oil spillage, Building lavatories and visionaries over running water or even the sea as it is the practice in some reverine areas, Radioisotopes, heavy metal, cyanide discharge, combustion, toxic waste disposal at sea, mineral Processing Plant (e.g. coal reduction), Eroded sediments, mining, Pesticides to pollution. The growth of human population, industrial and agricultural practices is the major causes of pollution (Eguabor, 1998). Water pollution becomes worse as a result of overcrowding in urban areas. Agricultural, domestic and industrial wastes are the major source of cyanide pollution. Sewage is the biggest pollutant of fresh water when discharged into them. Sewage is the waterborne waster of society and the discharge of untreated sewage into a river is very enormous and unhealthy. The flora and fauna of the rivers experience change and reduction in number due to death by suffocation (Tudge, 1991).

Highly polluted rivers have obnoxious smell and contain little or no flora or fauna. Another source of water pollution is the discharge of hot water from cooling engines in the industries. This increases water temperature and lowers the metabolic rate of organisms. Chemical pollutants from distaffs have been found to be animal carcinogenic.

Pollution poses a serious risk to life especially when the water is a source of drinking and for domestic purposes for humans. Polluted waters are potent agents of diseases such as cholera, typhoid and tuberculosis. This is why the guided discovery approach is a teaching strategy which when adequately utilized and combined with other methods of science teaching will leave lasting impression on the learner as well as help him solve the problems of his immediate environment (Ogwuazor, 1998).

Water pollution has a duel effect on nature. It has negative effects on the living and also on the environment. The effects of pollution on human beings and aquatic communities are many and varied. Water pollution causes approximately 14,000 deaths per day, mostly due to contamination of drinking water by untreated sewage. Diversity of communities is to be expected when large amount of toxic materials especially heavy metals, cyanide and so on are released into the streams, lakes and coastal waters in the ocean. Much of aquatic pollution involves sewage in which organic waste predominate. This waste can increase secondary productivity while altering the character of the aquatic community. Most fishes especially the species desired as food by man are among the sensitive species that disappear with the least intense pollution.

Water polluted by cyanide lead to damage on human health. Drinking water is affected and health hazards result. Acid rain which lowers the pH value of soil and emission of carbon dioxide cause ocean acidification, the ongoing decrease in the pH of the Earth's Oceans as CO₂ becomes dissolved.

The occurrence of cyanide contamination in water body and the environment at large has called for great concern in many countries across the globe including Nigeria as a nation. This toxic ionic compound does not only affect the water bodies like seas, lakes, reservoirs and ponds but enter the underground water in traceable amounts, and thereafter end up in plants and animals creating adverse effects on their systems.

In this research, a low cost agricultural waste, Shea Butter Seed Husk which was converted to modified carbon black (MCB) has been considered in the kinetic study for batch adsorption of cyanide ion from aqueous solution, hence creating a feasible and low cost remediation process.

2. METHODOLOGY

1.1 Materials

The raw material used for this research work shea butter (*Vitellaria paradoxa*) seed fruits were collected from Sabon Gida Tukura, Kurmi Local Government Area and Gidan Idi, Wukari Local Government, Taraba State, Nigeria. The *vitellaria p.* fruits were washed severally with surface water to remove attached films such as the fleshy layers, soil and dusts to expose the indehiscent seed cuticle (husk). The seed husks were removed by breaking/dehusking using mortar and pestle and washed with double distilled water and dried. For the preparation of the adsorbent, the dried and grinded sample was calcined at 500°C for physical preparation. Chemical activation of the prepared carbon black sample was done by mixing/treating it with dilute hydrochloric acid until paste was formed which was then carbonized again at a temperature of 650-700°C in the furnace for 2 hours. The black product obtained was dried in an oven for 12 hours at 100°C and passed through 750µm sieve size for regulating the uniform particles, hence, the carbonized sample was washed severally with de-ionized water until an approximate pH of 7 was attained, it was filtered with whatman No1 filter paper and again dried for 8hours at 110°C in the oven and stored as adopted by Nwabanne and Igbokwe (2012).

About 100mg of KCN in 1000ml was prepared from the stock solution of 6.56g KCN in 1000ml solution with KOH pellet. Other concentrations were prepared by serial dilution of the Cyanide (stock). All other chemicals used for the preparation of adsorbent and for adsorption tests were of analytical grade and were used without further purification.

1.2 Characterization of the Adsorbent

The physical properties, Ultimate analysis and surface morphology of the prepared activated carbon from *v. paradoxa* seed husk were studied and calculations presented in Table 1.

1.3 Adsorption Model: The adsorption models employed in this research work are basically categorized into two types: Based on Initial Concentration of the ions present termed the Equilibrium Model (EM) and based on Contact Time for the adsorption to reach equilibrium termed Kinetics Model (KM). These models are presented in Table 2.

Table 1: Ultimate Analysis and Physical Properties of Shea Butter Seed Husk

Physical Properties				Elemental Analysis			
Ash (%)	V _M (%)	FC (%)	M (%)	H	C	N	S

1.37	69.3	0.69	4.0	5.2	61.3	0.56	0.009
------	------	------	-----	-----	------	------	-------

V_M = Volatile Matter, M = Moisture Content, FC= Fixed Carbon

1.4 METHOD

Three sets of batch mode operation were conducted on prepared adsorbent in order to measure the adsorption behaviour of cyanide contained before and after adsorption. Thus, in a representative experiment, 0.5 - 4.0g of dried adsorbent was shaken with 100ml of the stock solution at varying concentration at 30°C for 90minutes. After equilibrium, the mixture was filtered and the filtrate was treated with prepared picric solution for colorimetric analysis for the remaining cyanide ions concentration. Ranges of operating parameters for the various batch operations are shown in Table 3.

Table 2: Equilibrium and Kinetic Models for Adsorption Processes

Model	Mathematical Expression	Parameters involved
Equilibrium Models (EM)		
Langmuir Model	$C_e/q_e = 1/Q^0 b + C_e/Q^0$	Q^0 is q_{max} (mg/g), and b (L/mg) is the Langmuir constants related to the capacity and energy of adsorption.
Halsey-Taylor (Freundlich) Model	$\log q_e = \log K_f + 1/n \log C_e$	K_f ((mg/g)/(mg/L)), and n are the constant
Henry Model	$q_e = K' C_e$	K' is a constant
Slygin-Frumkin (Temkin) Model	$q_e = B \ln A + B \ln C_e$	A and B are the temkin constant
Kinetic Models (KM)		
Pseudo First Order Model	$\log(q_e - q_t) = \log(q_e) - k_1 t / 2.303$	q_e and q_t are sorption capacities (mg/g) of adsorbent at equilibrium and at a given time " t ". k_1 is the pseudo-first order adsorption rate constant (s^{-1})
Pseudo Second Order Model	$t/q_t = 1/K_2 q_e^2 + t/q_e$	k_2 is the pseudo-second-order adsorption rate constant (g/mg s)
Intra Particle Diffusion Model	$q_t = K_i t^{1/2} + C$	q_t is sorption concentration at time t ; K_{id} is the rate constant of intra particle transport (mg/g/time ^{1/2}); C (mg/g) is the intercept that gives an idea about the thickness of the boundary layer.

Table 3: Time and Initial Cyanide Concentration Operating Parameters.

Batch Operation Objective	Operating Parameters
To study the effect of Initial Cyanide Concentration on Cyanide ion Removal	Adsorbent Dosage: 3.0g/100ml; Temp 30°C; Time 120min; pH 10; ICC: 100-600mg/L
To study the effect of Contact Time on Cyanide ion Removal	Adsorbent Dosage: 3.0g/100mg; Temp 30°C; ICC: 100mg/L; pH 10; Time: 15, 30, 45, 60, 75, 90, 105, 120 minutes.

Where ICC: Initial Cyanide Concentration

Adsorption isotherms of cyanide were measured by shaking (using mechanical shaker) 0.5-4.0g of the adsorbent in 100ml solution of 100mg/L concentration of cyanide for 90minutes. The Initial Cyanide Concentration (ICC) was also varied in the range between 100-600mg/L for the same time (90mins) at an adsorbent dose of 3.0g. Percentage adsorption for each sample was calculated according to Eq. (1), where C_i and C_e (mg/L) represents the initial and equilibrium concentration, respectively. The amount of adsorbed cyanides (q_e , mg/g) were calculated by the mass balance calculation of cyanide ion before and after the adsorption as expressed by Eq. (2). Where, V (L) is the volume of the test solution used and W (g) is the dry weight of the adsorbent.

$$\%A = \frac{C_i - C_e}{C_i} \times 100\% \quad (1)$$

$$Q = \frac{C_i - C_e}{W} \times V \quad (2)$$

$$R_L = \frac{1}{1 + bC_0} \quad (3)$$

Instrumental Analysis: Replicate samples were prepared in triplicates by transferring known amount of adsorbent into the solution in 250ml Erlenmeyer flask for statistical treatment, in which certain simple percentage was used to determine the amount of cyanide removal. , While determinate errors were minimized by running blank. Free cyanide and weak acid cyanide reacts with picric acid reagent to produce an orange colour that can be measured calorimetrically at the wavelength of 520nm (Microprocessor UV/VIS Single Beam Spectrophotometer model T60). The dissolved base/alkali metal picrate was converted by the cyanide to the coloured salt of isopurpuric acid.

3.0 RESULTS AND DISCUSSION

Equilibrium Models for Cyanide ions Adsorption onto Shea Butter Seed Husk (SBSH):

An adsorption isotherm represents the equilibrium relationship between the adsorbate concentration in the liquid phase and that on the adsorbents surface at a given concentration and operating conditions. To predict these equilibrium relations during the adsorption of cyanide from aqueous solutions, Langmuir, Halsey-Taylor, Henry and Slygin-Frumkin Adsorption Isotherms were tested. The various values for the parameters present in the isotherms used such as R^2 and others are presented in Table 4.

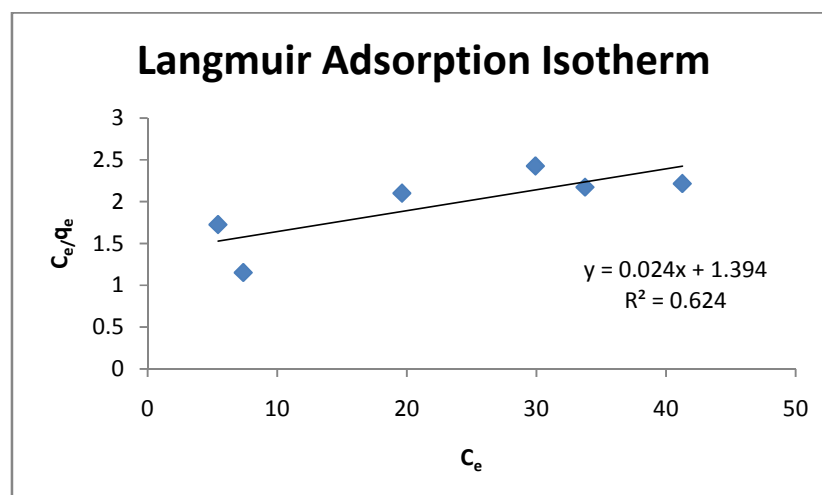


Figure 1: Langmuir Adsorption Isotherm for the Removal of Cyanide ions

The Langmuir adsorption isotherm for the adsorption of cyanide ions on Shea butter activated carbon is presented in Figure 1. The ratio of the equilibrium concentration to the ratio of the amount of iron adsorbed (C_e/Q_e) was plotted against the equilibrium concentration of cyanide (C_e). The linearity of the plot shows that Langmuir isotherm model can be used to predict the sorption of cyanide ions on Shea butter activated carbon. The Langmuir plots shows that there is increase in the rate of adsorption at different concentrations. This means that the lesser the concentration of the cyanide ions, the higher the adsorption of ions by the activated carbon. The Langmuir model assumes that the uptake of cyanide ions occurs on a homogeneous surface by monolayer adsorption without any interactions between adsorbed ions (Prabakaran and Arivoli, 2011). The Langmuir model parameters and the statistical fits of the adsorption data is presented in Table 4 and the correlation coefficient R^2 is less than 0.89 which reveals' that the isotherm is not consistent with Langmuir model.

The theoretical monolayer saturation capacity Q_0 for cyanide adsorption on activated carbon from Shea butter obtained from the slope was 41.667mg/g of carbon. The separation factor (R_L) was determined from equation 3, the values was 0.370. Since R_L is less than 1 for all the concentrations it means that adsorption process is favourable (Weber and Chakravorti, 1974).

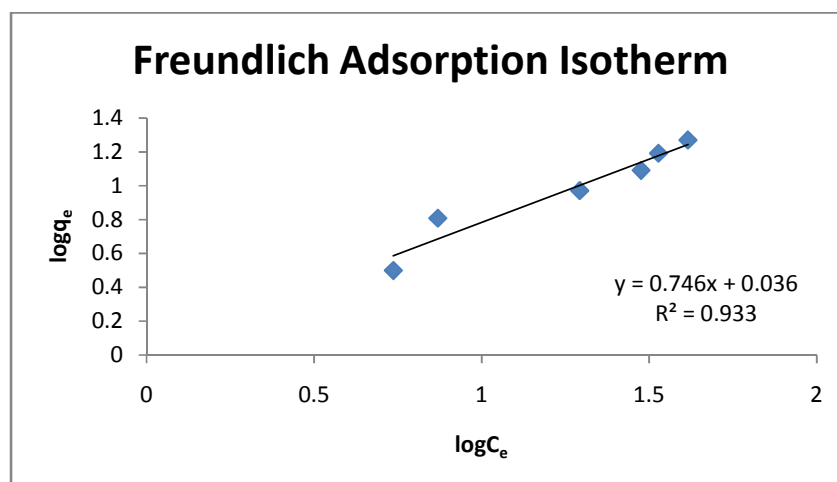


Figure 2: Halsey – Taylor (Freundlich) Adsorption Isotherm for the removal of Cyanide ions

Figure 2 and Table 4 shows the batch adsorption isotherm of cyanide ion on Shea butter activated carbon at 30°C. The log of Q_e amount of cyanide ions adsorbed at equilibrium was plotted against the log of the equilibrium concentration C_e of the cyanide ions adsorbed. The adsorption capacity K_f and the adsorption intensity $1/n$ are obtained directly from the slopes and intercepts of the linear plot. The linearity of the plot and high correlation coefficient R^2 obtained (0.933) which is also greater than 0.89 reveals that the isotherm is consistent with *Freundlich* model. Atef (2009) reported that R^2 greater than 0.89 shows that the adsorption data conforms to the model. The value of adsorption intensity ($n = 1.34$) is more than one for bamboo activated carbon.

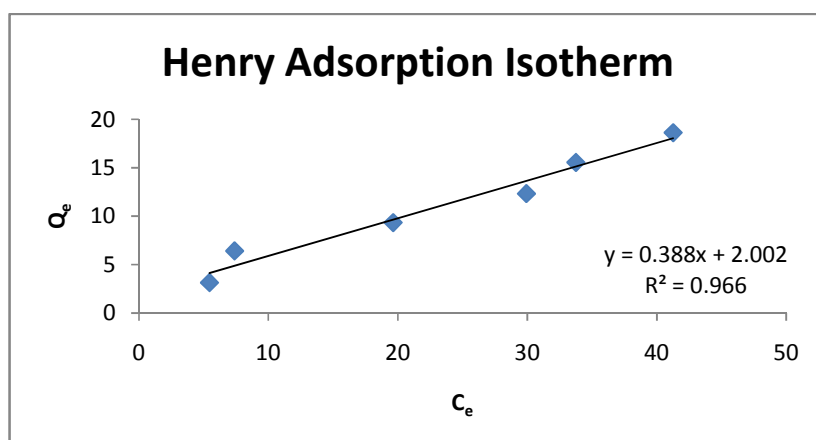


Figure 3: Henry Adsorption Isotherm for the removal of Cyanide ions

Figure 3 and Table 4 shows the batch adsorption isotherm of cyanide ion on Shea butter activated carbon at 30°C. Q_e amount of cyanide ions adsorbed at equilibrium was plotted against the equilibrium concentration C_e of the cyanide ions adsorbed. The linearity of the plot and high correlation coefficient R^2 obtained (0.966) which is also greater than 0.89 reveals that

the isotherm is consistent with *Henry Adsorption Model*. Atef (2009) reported that R^2 greater than 0.89 shows that the adsorption data conforms to the model.

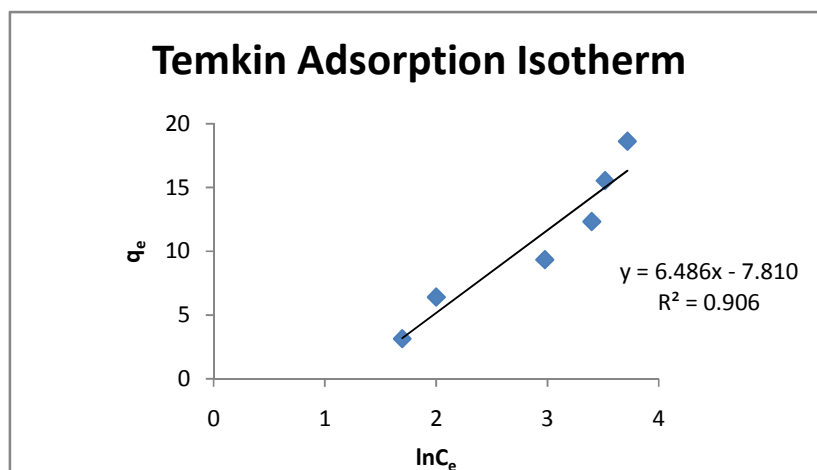


Figure 4: Slygin-Frumkin (Temkin) Adsorption Isotherm for the removal of Cyanide ions

A linear relationship was also exhibited from the plot of amount of cyanide adsorbed (Q_e) at equilibrium against the natural logarithm of equilibrium concentration of cyanide ions ($\ln C_e$). Similarly the correlation coefficient R^2 (0.906) obtained for Temkin adsorption isotherm model for cyanide ions in Figure4 and Table 4 shows that the Temkin model can also be used to predict the sorption of cyanide ions using Shea butter seed husk activated carbon.

Table 4: Equilibrium Model Parameters and their values for the various Adsorption Isotherms

Isotherms	Parameters	Values
Langmuir	R^2	0.624
	Q^o	41.667
	b	0.017
	R_L	0.367
Slygin-Frumkin (Temkin)	R^2	0.909
	A	0.300
	B	6.486
Halsey-Taylor (Freundlich)	R^2	0.933
	n	1.340
	$1/n$	0.746
	K_f	1.086
Henry	R^2	0.966
	K'	0.388

In this research work, the R_L value calculated as per given formula in the studied range of cyanide concentration are found to be 0.367 which falls in the range of 0 – 1, which suggests the favourable sorption of cyanide ions onto the studied Shea Butter Seed Husk, under the conditions used for the operation. For the Shea Butter Seed Husk (SBSH), the $1/n$ value is approximately 0.746 (<1), which indicates a favourable sorption. The present data fit the Henry, Freundlich, and Temkin isotherm models for Shea Butter Seed Husk, in the following order Henry (0.966) > Freundlich (0.933) > Temkin (0.909).

Kinetics Models for Cyanide ions Adsorption onto Shea Butter Seed Husk:

To find out a suitable kinetic model for explaining the cyanide ions adsorption process Pseudo-First Order Model, Pseudo-Second Order Model and Intra Particle Diffusion Model were tested. The various values for the parameters present in the models used such as R^2 and others are presented in Table 5.

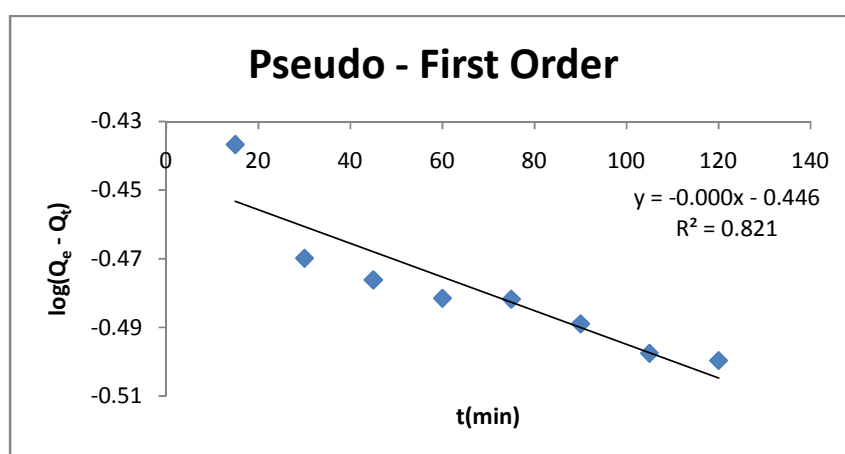


Figure 5: Pseudo-First Order Model for the removal of Cyanide ions by SBSH

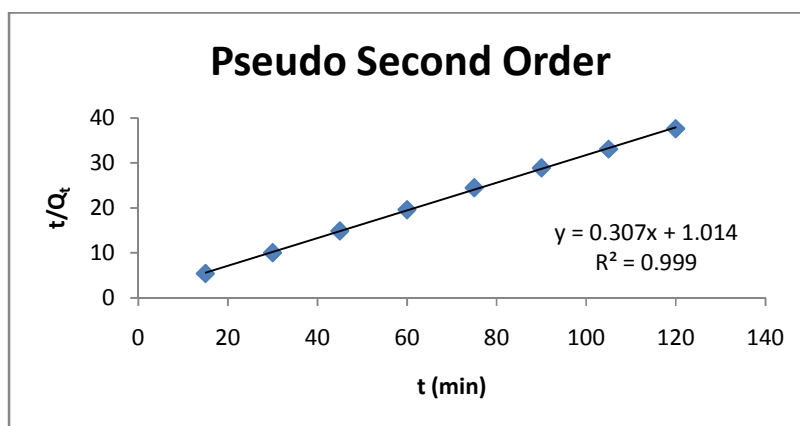


Figure 6: Pseudo-Second Order Model for the removal of Cyanide ions by SBSH

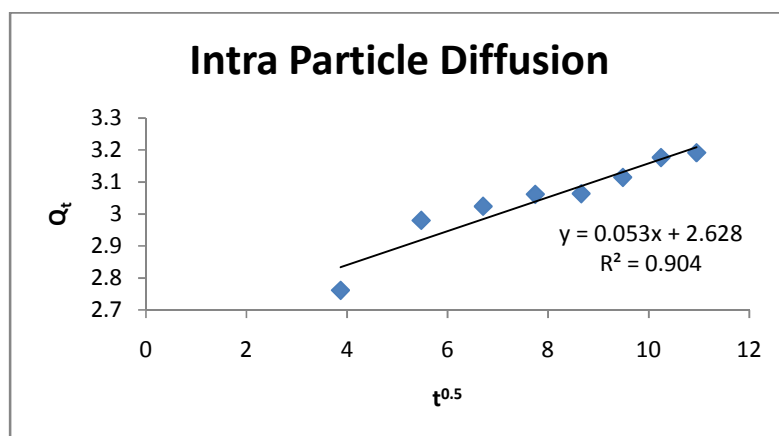


Figure 7: Intra Particle Diffusion Model for the removal of Cyanide ions by SBSH

Table 5: Kinetic Model Parameters and their values for the various Adsorption Models

Models	Parameters	Values
Pseudo-First Order	(C_o) mg/l	100
	R^2	0.821
	q_e	0.358
	K_1	0
Pseudo-Second Order	(C_o) mg/l	100
	R^2	0.999
	q_e	3.257
	K_2	0.093
Intra Particle Diffusion	(C_o) mg/l	100
	R^2	0.904
	K_1	0.053
	C	2.628

Kinetic parameters for the above model equations are computed from the slope and intercept of the respective figures as stated above and are reported in Table 5 along with the values of correlation coefficients (R^2). From Table 5, it is crystal clear that Pseudo - First Order Model, Pseudo-Second Order Model and Intra Particle Diffusion Model shows R^2 value of 0.821, 0.999 and 0.904 respectively. From the values calculated, it will deduced that, Pseudo – Second Order Model best describes the kinetics of adsorption of cyanide ions by Shea Butter Seed Husk with the highest value of R^2 to be 0.999 as against others.

4 CONCLUSION

From the result and discussion, it showed doubtlessly the effectiveness of the prepared and modified adsorbent in the decontamination of wastewater bearing cyanide ions. The maximum sorption capacity of the adsorbent was seen to emerge at about 94.56% cyanide removal at 100mg/L concentration with adsorbent dose of 3.0g/100ml. The equilibrium and kinetic studies showed that a greater adsorption capacity of cyanide ion from aqueous solution. The equilibrium and kinetic stage adsorption by Henry Isotherm and Pseudo-second Order Model are more accurate for the cyanide ions removal by the SBSH as adsorbent. Hence, the adsorption study behaviour of modified Shea butter seed husk adsorbent shows its potential ability in the treatment of wastewater (effluent) bearing cyanide ions.

REFERENCES

- 1.ATSDR, CERCLA (2007); priority list of hazardous substances, Available at:<http://www.atsdr.cdc.gov/cercla/07list.html> (accessed 11.01.2010)
- 2.Dursun A.Y., Alik A.C., Aksu Z. (1999), Degradation of ferrous(II) cyanide complex ions by *Pseudomonas fluorescens*, *Process Biochem*, (34), 901–908
- 3.Effluent guideline and standards given in title 40, section 400-475, *Code of Federal Regulations*, 2008.
- 4.Eguabor, V (1998). Strategies for Teaching water pollution in secondary schools. *STAN Journal Environmental Education series* (2), 49
- 5.Faisal M., and Hasnain, S. (2004). Microbia conversion of Cr(vi) into Cr(iii) in industrial effluent. *African J. Biotechnol.* 3(11): 610 – 617.
- 6.Gbamanja S.P.T. (1998). The Pedagogy of water pollution. *STAN Journal “Environmental Education Series”* (2), 43
- 7.Gbehe, N.T. (2004). “Land Development in Nigeria: An Examination of Environmental Degradation Associated with land use Types. *Conference Paper* at the Department of Geography Benue State University (B.S.U.) Makurdi. January 2004.
- 8.Ogwuazor, K.E. (1998). Teaching water pollution by guided discovery. *STAN Journal Environmental Education Series* (2) 52.
- 9.Olaniran N.S. (1995). “Environment and Health: An Introduction”, in Olaniran, N.S. etal (Ed) Environment and Health.
- 10.Ramya, R. Sankar, P, Anbalagan, S, Sudha, P. N (2011), *International Journal of Environmental Sciences*, 1323-1338, 1(6).
- 11.Reddy, K.R., Adams, J.F., Richardson, C., (1999). Potential Technologies for Remediation of Brownfield. *Practice Periodical of Hazardous, Toxic, and Radioactive Waste Management* 3(2), 61-68
- 12.Reed, B.F., Arnnachalam, S., and Thomas, B. (1994). Removal of Lead and Chromium from aqueous waste streams using Grannular activated carbon (GAC) columns. *Environ. Prog.* 13: 60 – 65.
- 13.Riser-Roberts, E., (1998). Remediation of Petroleum Contaminated Soil: Biological, Physical, and Chemical Processes, Lewis Publishers, Boca Raton, FL.
- 14.Tudge, (1991). Source of pollution: The flora and fauna of the rivers experience change and reduction in number due to death by suffocation.
- 15.Weber T. W and Chatravorti R.K (1974) Pore and solid diffusion models for fixed bed adsorbers *journal of American Institute of Chemical Engineering* 20 : 228-238.
- 16.Webster.com.(2010). Definition from Webster Dictionary 08-13 Retrieved 2010-08-26
- 17.Young C.A. and Jordan T.S. (2004), Cyanide remediation: current and past technologies Proceedings of the 10th Annual Conference on *Hazardous Waste Research*: 104-129