Comparative Study of Lead (II) Removal from Aqueous Solution Using Different Adsorbents

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ABSTRACT

Adsorption of lead(II) from wastewater effluents using indigenous cellulose based waste biomass, such as nipa palm nut (NPN), palmyra palm nut (PPN), oil palm empty fruit bunch (EFB), oil palm fibre (OPF), and oil palm shell (OPS), as potential raw materials for the preparation of activated carbons was studied. Chemical activation method was used in preparing the activated carbon. The influence of various factors namely pH, adsorbent dosage, contact time, initial ion concentration and adsorbent particle size was studied to identify the adsorption capacity of the adsorbents. The amount of Pb^{2+} adsorbed increased with increase in adsorbent dosage, and contact time and decreased with increase in particle size and initial ion concentration. The optimum pH was obtained at pH6 for all the adsorbents. The result of adsorption studies showed that activated carbons produced from OPS and NPN are the most efficient adsorbents for the removal of Pb^{2+} from aqueous solutions. Adsorption data were modeled using Langmuir, Freundlich, Temkin and Dubinin-Radushkevich equations. Equilibrium data fitted well to the Freundlich, Langmuir and Tempkin models. The equilibrium data were best described by Freundlich model. It is seen from the study that all the adsorbents can be used as low-cost adsorbents for the removal of Pb^{2+} from aqueous solution.

Key words: Adsorption, lead, adsorbents, isotherm, removal, activated carbon

1. INTRODUCTION

Activated carbons are the most widely used industrial adsorbent for removing pollutants from gaseous, aqueous and non aqueous streams, due to their uniquely powerful adsorption properties and the ability to readily modify their surface chemistry [1]. Activated carbons are amorphous solid adsorbents that can be produced from almost all carbon-rich materials, including wood, fruit stones, peat, lignite, anthracite, shells and other raw materials [1]. Its unique adsorption properties result from its high-surface area, adequate pore size distribution, broad range of surface functional groups, and relatively high mechanical strength. These unique characteristics are responsible for its adsorptive properties, which are exploited in many different liquid-and gas-phase applications [2].

There are two main methods for the preparation of activated carbons. These are physical and chemical activation methods. Physical activation occurs in two stages – thermal decomposition or carbonisation of the precursor and controlled gasification or activation of the crude char. The carbonisation process causes some increase in porosity, although this is generally insufficient for practical use, and serves to modify the pore structure inherent to the precursor, as opposed to creating it [3]. During carbonization, most of the non-carbon elements such as oxygen, hydrogen, nitrogen and sulphur are eliminated as volatile gaseous products by the pyrolytic decomposition of the source raw material to produce a carbon skeleton possessing a latent pore structure [2, 4]. The activation process helps to develop further this structure by selective gasification of carbon, usually in temperature range of 600-1200^{0}C in steam, CO_2 or O_2 or mixtures of these. Chemical activation involves the treatment of the initial material with a dehydrating agent, such as sulphuric acid, phosphoric acid, zinc chloride, potassium hydroxide, or other substances, at temperatures varying from 400 to 1000^{0}C, followed by the elimination of the dehydrating agent by meticulous washing [1]. With chemical activation, relevant reactions involve attack on the cellulosic structures in the precursor. Recently, preparation of activated carbons from agricultural by products has been given serious attention due to the growing interest in low cost activated carbons from renewable biomass, especially for applications concerning treatment of drinking water and wastewater [5]. These agricultural wastes (waste biomass) impact negatively on the environment because of indiscriminate disposal of such wastes. Hence producing activated carbon from these wastes is an alternative method of waste reduction and reuse. The contamination of water by toxic metals through the discharge of industrial wastewater is becoming a serious environment problem in Nigeria. Heavy metals ions are reported as priority pollutants, due to their mobility in natural water ecosystems and due to their toxicity. The presence of these heavy metals in streams and surface waters has been responsible for several health problems with animals, plants and human beings. Lead is a pollutant that is present in drinking water and in air. In air, it is derived from lead emissions from automobiles because it is used as an anti knocking agent in the form of lead tetraethyl in gasoline. In water, lead is released in effluent from lead treatment and recovery industries, especially from lead battery manufacturing units. Lead is toxic to living organisms and if released into the environment can both accumulate and enter the food chain. Lead is known to cause mental retardations, reduces haemoglobin production necessary for oxygen transport and it interferes with normal cellular metabolism [6]. Lead has damaging effects on body nervous system. Several methods such as ion exchange, solvent extraction, reverse osmosis, precipitation, and adsorption have been proposed for the treatment of wastewater contaminated with heavy metals [7]. Among several chemical and physical methods, the adsorption onto activated carbon has been found to be superior to other techniques in water-re-use methodology because of its capability for adsorbing a broad range of different types of adsorbates efficiently, and its simplicity of design [8]. The aim of this study is to compare the performance of these five adsorbents in the adsorption of lead (II) from aqueous solution.

2. MATERIALS AND METHODS

2.1 Sourcing and pre-treatment of raw materials

The raw materials used for the preparation of activated carbon are oil palm shell (OPS), oil palm fibre (OPF), oil palm empty fruit bunch (EFB), nipa palm nut (NPN) and palmyra palm nut (PPN). Oil palm shell, oil palm fibre and oil palm empty fruit bunch were obtained from Ichida women co-operative oil processing mill, Ichida, Anambra State, Nigeria. Nipa palm nuts were obtained from a mangrove in Nkpogu village, Rivers State while Palmyra palm nuts were obtained from Nnamdi Azikiwe University, Awka, Anambra State, Nigeria. The raw materials were washed several times using de-ionized water to remove all traces of impurities, oil, dirt, dust, etc. The materials were dried in the sun for 72 hours to remove excess water until constant weight was obtained.

2.2 Production of activated carbon

The washed and dried raw materials were ground into fine particles using a Jencod grinding machine and sieved to a particle size of 300µm. 200g of sample was impregnated with concentrated orthophosphoric acid at the acid/precursor ratio of 0.4:1 (wt basis) for OPS and 2:1 for other materials. The impregnated samples were dried in an oven at 120^{0}C for 24hrs. The dried samples were carbonized in a Muffle furnace for 1hr at 500^{0}C for NPN, 2hrs at 500^{0}C for PPN and 2hrs at 800^{0}C for EFB, OPF and OPS. After cooling to the ambient temperature, the samples were washed with de-ionized water several times until pH 6-7, filtered with Whatman No.1 filter paper and then dried in the oven at 110^{0}C for 8hours. The samples were crushed and passed through different sieve sizes and then stored in a tight bottle ready for use.

2.3 Characterization of activated carbon

The pH of the carbon was determined using standard test of ASTM D 3838-80 [9]. Moisture content of activated carbon and raw materials was determined using ASTM D 2867-91[10].The bulk density of the activated carbon was determined according to the tamping procedure by Ahmedna et al [11]. The volatile content was determined by weighing 1.0g of sample and placing it in a partially closed crucible of known weight. It was then heated in a muffle furnace at 900^{0}C for 10mins.The percentage fixed carbon was determined as 100 – (Moisture content + ash content + volatile matter). The iodine number was determined based on ASTM D 4607-86 [12]] by using the sodium thiosulphate volumetric method The specific surface area of the activated carbon was estimated using Sear's method [13, 14] by agitating 1.5g of the activated carbon samples in 100ml of diluted hydrochloric acid at a pH = 3. Then a 30g of sodium chloride was added while stirring the suspension and then the volume was made up to 150ml with deionized water. The solution was titrated with 0.1N NaOH to raise the pH from 4 to 9 and the volume, V recorded. The surface area according to this method was calculated as S = 32V – 25. Where, S = surface area of the activated carbon, V = volume of sodium hydroxide required to raise the pH of the sample from 4 to 9.

2.4 Adsorbate preparation and batch adsorption studies

The sample ($Pb(NO_3)_2$ was dried in an oven for 2hrs at 105^{0}C to remove moisture. The simulated wastewater effluent was produced by dissolving 1.6g of $Pb(NO_3)_2$ in 1000ml of de-ionized water to get the stock solution of 1000g/l. 0.5g of activated carbon was added to 100ml of the 100mg/l of adsorbate in a conical flask and placed on a magnetic stirrer. The stirring was done at 30^{0}C for 2hrs. After adsorption was complete, the solution was filtered using Whatman no.1 filter paper. The residual Pb^{2+} concentrations of the effluent were determined spectrophotometrically using Atomic Absorption Spectrophotometer at 217.0nm wavelength. The adsorption capacity, q_e (mg/g) and percentage adsorbed were calculated from equation 1 and equation 2 respectively.

$$q_e = [(C_o - C_e)\, V / m] \qquad 1$$

$$\%\ Adsorbed = [(C_o - C_e)/C_o]\ x\,100 \qquad 2$$

Where, C_o and C_e are the metal concentrations (mg/l) at initial and any time t, respectively, V the volume of the solution (L), and m the mass of adsorbent used (g).

2.4.1 Effect of particle size

The effect of particle size on the sorption of Pb^{2+} was investigated by changing the particle size in the range of 150 to 1100µm with initial concentration of 100mg/l and adsorbent dosage of 0.5g for 2hrs.

2.4.2 Effect of adsorbent dosage

Initial ion concentration of 100mg/l was used in conjunction with adsorbent dosage 0.2, 0.35, 0.5, 1.0, 1.5 and 2.0g for contact time of 2hrs and particle size of 150µm.

2.4.3 Effect of pH

The effect of pH on the sorption was studied at pH 3, 4, 5, 6, 7, 8 with 0.5g of adsorbent dosage, for 2hrs.

2.4.4 Effect of contact time

The effect of contact time was investigated for 10, 20, 40, 60, 90, 120, 150 and 180 min at pH 6, 0.5g/100ml sample dosage and at temperatures of 30-50^{0}C.

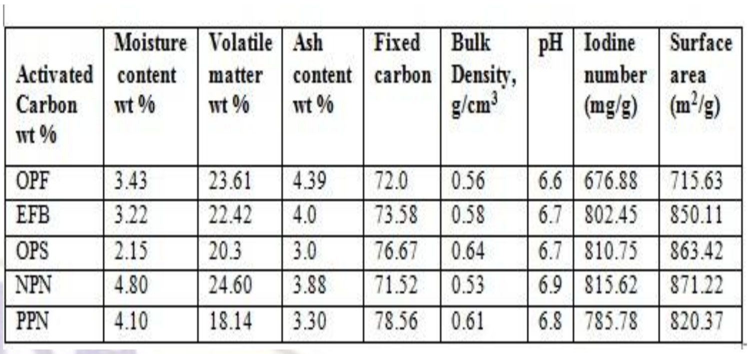
2.4.5 Effect of initial ion concentration

The effect of initial Pb^{2+} concentration on the sorption was investigated by changing the initial ion concentration in the range of 100-750mg/l with 150µm particle size, adsorption dosage of 0.5g and at 30-50^{0}C for 2hrs.

3. RESULTS AND DISCUSSION

Physico-chemical characteristics of activated carbons are shown in Table 1. It can be observed that OPS had the lowest moisture and ash contents and high surface area of 863m^2/g and iodine value of 810.75 mg/g. NPN had the lowest bulk density and fixed carbon, and highest surface area and iodine number. OPF had the lowest iodine number and surface area. The presence of ash has been shown to inhibit surface development [15]. Consequently low surface area is observed in carbons with high ash content [16]. The raw material, the particle size range used and the degree of activation affect bulk density, which does have an effect on adsorption per unit volume [17]. The iodine number value is an indication to surface area of the activated carbon [18]. The larger the surface area is, the greater is the adsorption capacity.

Table 1: Physico-chemical characteristics of the activated carbons



Activated Carbon wt %	Moisture content wt %	Volatile matter wt %	Ash content wt %	Fixed carbon	Bulk Density, g/cm^3	pH	Iodine number (mg/g)	Surface area (m^2/g)
OPF	3.43	23.61	4.39	72.0	0.56	6.6	676.88	715.63
EFB	3.22	22.42	4.0	73.58	0.58	6.7	802.45	850.11
OPS	2.15	20.3	3.0	76.67	0.64	6.7	810.75	863.42
NPN	4.80	24.60	3.88	71.52	0.53	6.9	815.62	871.22
PPN	4.10	18.14	3.30	78.56	0.61	6.8	785.78	820.37

3.1 Batch adsorption studies

3.1.1 Effect of adsorption dosage on the adsorption process

Adsorption dosage is an important parameter as it determines the capacity of an adsorbent for a given initial concentration of the adsorbate. The result showed that as the adsorbent dosage increased, the percentage of adsorption also increased but the amount adsorbed per unit mass of the adsorbent decreased considerably (Figure 1). The decrease in unit adsorption with increasing dose of adsorbent is attributed to adsorption sites remaining unsaturated during the adsorption reaction [19]. Figure 1 reveals a definite increase in the adsorption capacity of the adsorbents with dosage. This is as a result of the larger number of available adsorption sites favouring the enhanced uptake of the metal ions [20]. The authors stated that the dependence of adsorption on doses can be explained in terms of the concentration factor involving low metal-to-adsorbent ratio at low metal concentrations. At higher concentrations, the available sites of adsorption become fewer and hence the percentage of metal ion removed is dependent upon the initial concentration. Many workers have reported similar results [21, 22, 23].

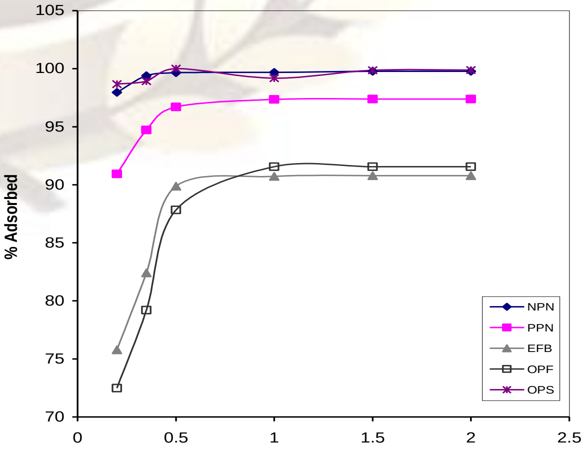


Figure 1: Effect of adsorbent dosage on the adsorption of Pb^{2+} on the adsorbents

3.1.2 Effect of particle size on the adsorption process

The removal of Pb^{2+} at different particle sizes showed that the removal rate increased as particle size deceased (Figure2). This same trend was reported by different authors [23, 24]. The relatively higher adsorption with smaller adsorbate is explained by the fact that smaller particle yields large surface area. According to Weber and Morris [20], the breaking of larger particles tends to open tiny cracks and channels on the particle surface of the material resulting in more accessibility to better diffusion, owing to the smaller particle size. OPS and NPN gave the best performance in removal of Pb^{2+} from aqueous solution. This may be attributed to their high surface areas.

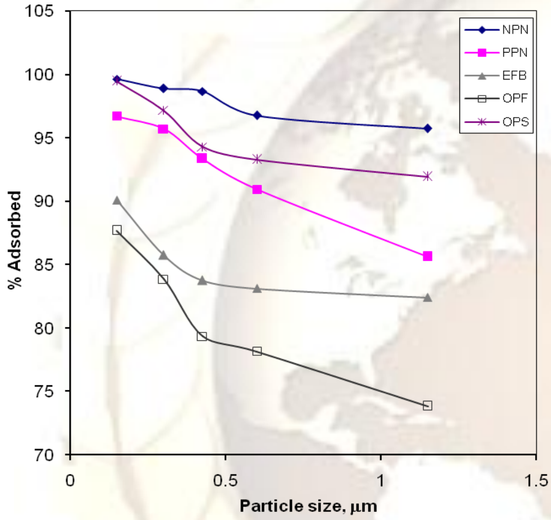


Figure 2: Effect of particle size on the adsorption of Pb^{2+} on the adsorbents

3.1.3 Effect of pH on the adsorption process

pH is one of the most factors influencing not only site dissociation, but also the solution chemistry of heavy metal. Figure 3 presents the effect of pH on the removal of Pb^{2+} by the different adsorbents. The adsorption of the Pb^{2+} increased with increasing pH. The maximum Pb^{2+} adsorption for all the adsorbents was obtained at pH 6. Pb^{2+} adsorption decreased as pH rose beyond the optimum pH of 6. Above pH 6, Pb(II) started precipitating as $Pb(OH)_2$. Similar result was reported by Liu et al [25].The increase in adsorption capacity of Pb(II) with increasing pH is attributable to two possible mechanisms, which are cation exchange and surface complexation mechanisms. At pH above 6, adsorption onto OPS was still high in comparison with other adsorbents.

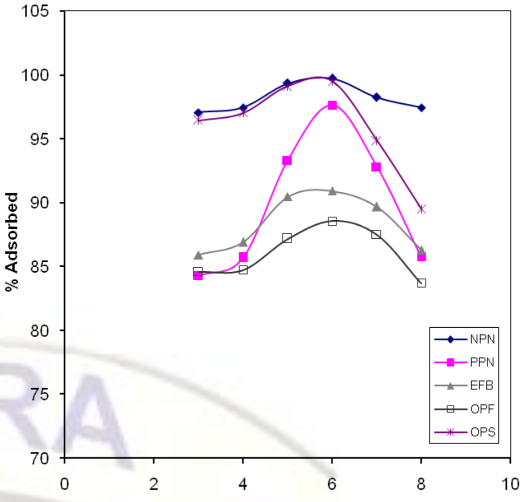


Figure 3: Effect of pH on the adsorption of Pb^{2+} on the adsorbents

3.1.4 Effect of initial ion concentration on the adsorption process

The initial metal concentration of an effluent is important since a given mass of sorbent can only adsorb a fixed amount of heavy metal. From Figure 4 it is seen that the adsorption percentage decreased with increase in initial ion concentration. However, the amount of Pb^{2+} adsorbed increased with increase in initial ion concentration. The lead (11) adsorbed by OPS was above 95% irrespective of the initial ion concentration as seen in Figure 4. This shows that OPS is a very good adsorbent for Pb^{2+} adsorption.

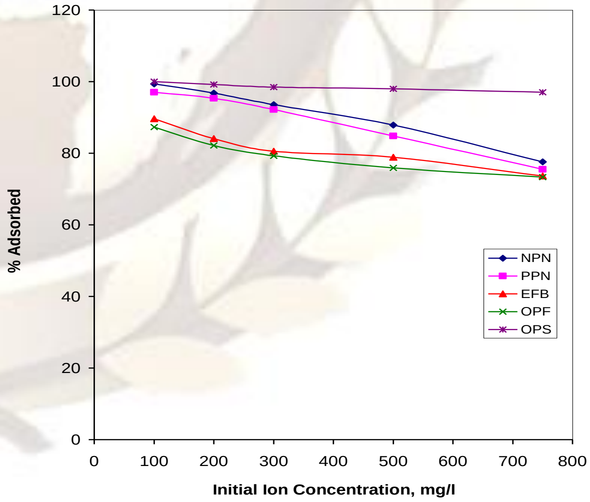


Figure 4: Effect of initial ion concentration on the adsorption of Pb^{2+} on the adsorbents

3.1.5 Effect of contact time on the adsorption process.

The result of percentage Pb^{2+} adsorbed is shown in Figure 5. It was found that the Pb^{2+} adsorption percentage increased with increasing contact time. Above 75% of Pb^{2+} adsorption occurred in the first 10 to 60mins for all the adsorbents and thereafter the rate of adsorption of the adsorbate species into the adsorbent was found to be slow. The time required to reach equilibrium on Pb^{2+} adsorption was 90, 90, 120, 120 and 90mins for NPN, PPN, EFB, OPF and OPS respectively. The initial rapid adsorption is due to the availability of the positively charged surface of the adsorbents for adsorption of anionic Pb^{2+} species present in the solution. The later slow adsorption is probably due to the electrostatic hindrances between adsorbed negatively charged adsorbate species into the surface of adsorbents and the available anionic adsorbate species in solution, and the slow pore diffusion of the solute ion into the bulk of the adsorbent [26].

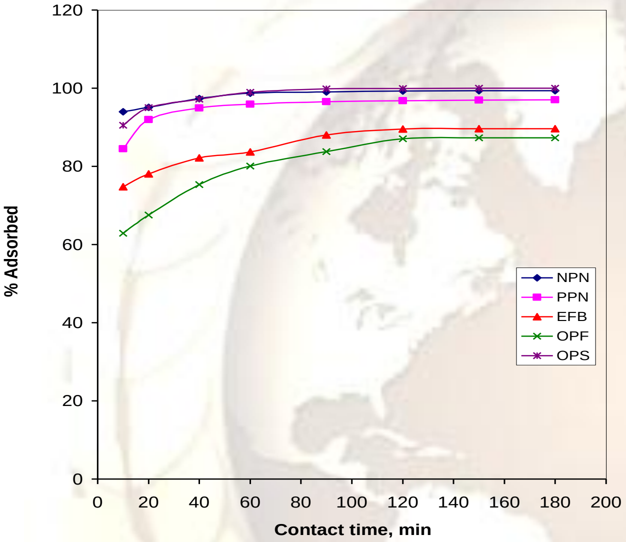


Figure 5: Effect of contact time on the adsorption of Pb^{2+} on the adsorbents

3.2 Isotherm studies

The equilibrium adsorption isotherm is important in the design of adsorption systems [19]. In general, the adsorption isotherm describes how adsorbate interact with adsorbents and this is critical in optimizing the use of adsorbents, The relationship between the amount of a substance adsorbed at constant temperature and its concentration in the equilibrium solution is called the adsorption isotherm.

3.2.1 Langmuir isotherm model

The Langmuir adsorption model is given by:

$$q_e = Q \frac{b\,C_e}{1 + b\,C_e} \qquad 3$$

The Langmuir equation can be described by the linearized form [23, 27]

$$\frac{C_e}{q_e} = \frac{1}{Q_o b} + \left(\frac{1}{Q_o}\right) C_e \qquad 4$$

Where C_e is the equilibrium concentration of the adsorbate, q_e the amount of adsorbate per unit mass of adsorbent (mg/g), and Q_0 and b are Langmuir constants related to adsorption capacity and rate of adsorption, respectively. When C_e/q_e is plotted against C_e, straight line with slope $1/Q_0$ indicates that adsorption follows the Langmuir isotherm. The Langmuir constants, Q_0 and b were evaluated from the intercept and the slope of the linear plot of experimental data of ${}^1/q_e$ versus ${}^1/c_e$ and presented in Table 2 to 6. The essential characteristics of the Langmuir equation can be expressed in terms of a dimensionless separation factor, R_L, defined as [28].

$$R_L = \frac{1}{1 + bC_O} \qquad 5$$

Where, C_o is the initial ion concentration, b the Langmuir's adsorption constant (L/mg).The R_L value implies the adsorption to be unfavourable ($R_L > 1$), Linear ($R_L = 1$), favourable ($O < R_L < 1$), or irreversible ($R_L = 0$) [22]. R_L values for Pb^{2+} on the adsorbents were less than 1 and greater than zero indicating favourable adsorption under conditions used in this study. The correlation coefficients showed that Pb^{2+} adsorption on adsorbents follow Langmuir model. Results obtained by some researchers showed that experimental data conformed to Langmuir model [23, 25].

3.2.2 Freundlich isotherm model

The Freundlich adsorption isotherm can be written as [29]:

$$q_e = K_F C_e^{1/n} \qquad 6$$

A linear form of this expression is

$$\log\ q_e = \log K_F + {}^1/_n \log C_e \qquad 7$$

Where K_F and n are Freundlich constants, n giving an indication of how favourable the adsorption process is and K_F is the adsorption capacity of the adsorbent. K_F and n are determined from the linear plot of log q_e versus log C_e. From the linear plots of Inq$_e$ versus InC$_e$, values of Freundlich constants K_F and n were calculated from the intercept and slope, respectively, and are presented in Tables 2 to 6. The K_F which is a measure of adsorption capacity, increased with temperature for Pb^{2+} adsorption. The magnitude of the exponent, n gives an indication of the favourability and capacity of the adsorbent/adsorbate system. Karthikeyan et al [20] has reported that n values between 1 and 10 represent favourable adsorption conditions. In this work, in all cases, the exponent is 1<n<3, showing beneficial adsorption for the system. The correlation coefficients, R^2 ranging from 0.965 to 0.999 indicates that Pb^{2+} adsorption followed Freundlich model. Similar results were obtained by other authors [22, 26, 27, 28].

3.2.3Temkin isotherm

The Temkin isotherm has been used in the following form [30]:

$$q_e = \frac{RT}{b} In(AC_e) \qquad 8$$

A linear form of the Temkin isotherm can be expressed as:

$$q_e = \frac{RT}{b} In\,A + \frac{RT}{b} In\,C_e \qquad 9$$

Where RT/b = B and A is Temkin constant, l/g. The adsorption data can be analyzed according to equation 10 and the constant B determines the heat of adsorption. The values of Temkin constants A and b as well as the correlation coefficients are listed in Tables 2 to 6. All correlation coefficients were greater than 0.904. Generally, data fairly conformed to Temkin isotherm model. The values of constants A and b obtained in this work are similar to the values obtained by Sekar et al [23]. The values of A and b increased with increase in temperature for Pb^{2+} adsorption.

3.2.4 Dubinin-Radushkevich isotherm model

The Dubinin – Radushkevich equation has the following form:

$$q_e = q_m e^{-\beta\varepsilon^2} \qquad 10$$

A linear form of Dubnin – Radushkevich equation isotherm [27] is:

$$Inq_e = Inq_m - \beta\varepsilon^2 \qquad 11$$

Where q_m is the Dubinin – Radushkevich monolayer capacity $(mmol/g)$, β a constant related to sorption energy, and ε is the Polanyi potential which is related to the equilibrium concentration as follows:

$$\varepsilon = RT\ In\left(1+\frac{1}{C_e}\right) \qquad 12$$

Where, R is the gas constant (8.314J/molK) and T is the absolute temperature. The constant β gives the mean free energy, E, of sorption per molecule of the sorbate when it is transferred to the surface of the solid from infinity in the solution and can be computed using relationship [29].

$$E = \frac{1}{\sqrt{2\beta}} \qquad 13$$

Dubinin-Radushkevich isotherm equation has been used for the sorption of metal ions on surfactant – modified montmorillonite and sorption of acid dyes on activated carbon [29, 30]. The Dubinin-Radushkevich constants were evaluated and given in Tables 2 to 6. The correlation coefficients presented in Tables 2 to 5 ranged from 0.569 to 0.763, indicating that the adsorption of Pb^{2+} did not follow the Dubinin-Radushkevich isotherm. If the mean free energy, E is <8KJ/mol, the adsorption is physisorption and if the energy of activation is 8-16KJ/mol, the adsorption is chemisorption in nature [27, 31]. The values of E obtained indicated that adsorption of Pb^{2+} on all the adsorbents was physisorption. B values obtained in this work are similar to the values obtained by Sivakumar and Palanisamy [27].

Table 2: Calculated isotherm parameters for the adsorption of Pb^{2+} on NPN

Isotherm model	**Temperature, K**		
	303	313	323
Langmuir			
Q (mg/g)	125	142.85	142.85
b (L/mg)	0.0620	0.0583	0.0625
R_L	0.1389	0.1464	0.1379
R^2	0.986	0.984	0.985
Temkin			
b (J/mg)	135.22	139.10	143.30
A (L/g)	1.864	2.017	2.147
R^2	0.942	0.941	0.945
Freundlich			
n	2.907	2.915	2.9326
K_f (L/g)	20.464	21.086	21.627
R^2	0.999	0.998	0.997
Dubinin-Radushkevich			
q_D (mg/g)	70.246	70.598	71.307
β (mol^2/J^2)	$4x10^{-7}$	$3x10^{-7}$	$3x10^{-7}$
E (KJ/mol)	0.0001	0.0001	0.0001
R^2	0.665	0.665	0.669

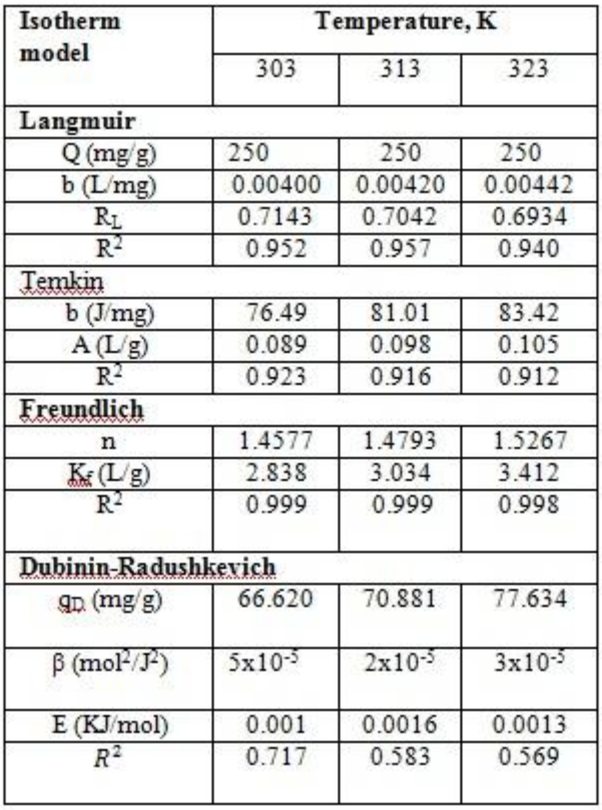
Table 3: Calculated isotherm parameters for the adsorption of Pb^{2+} on PPN

Isotherm model	**Temperature, K**		
	303	313	323
Langmuir			
Q (mg/g)	142.85	142.85	142.85
b (L/mg)	0.0343	0.0909	0.0387
R_L	0.2257	0.0991	0.2053
R^2	0.990	0.984	0.990
Temkin			
b (J/mg)	107.93	112.07	115.25
A (L/g)	0.567	0.604	0.636
R^2	0.986	0.980	0.987
Freundlich			
n	2.3420	2.3310	2.3753
K_f (L/g)	13.122	13.305	14.028
R^2	0.978	0.980	0.979
Dubinin-Radushkevich			
q_D (mg/g)	73.186	73.113	72.385
β (mol^2/J^2)	$3x10^{-6}$	$3x10^{-6}$	$2x10^{-6}$
E (KJ/mol)	0.0004	0.0004	0.0005
R^2	0.763	0.751	0.734

Table 4: Calculated isotherm parameters for the adsorption of Pb^{2+} on EFB

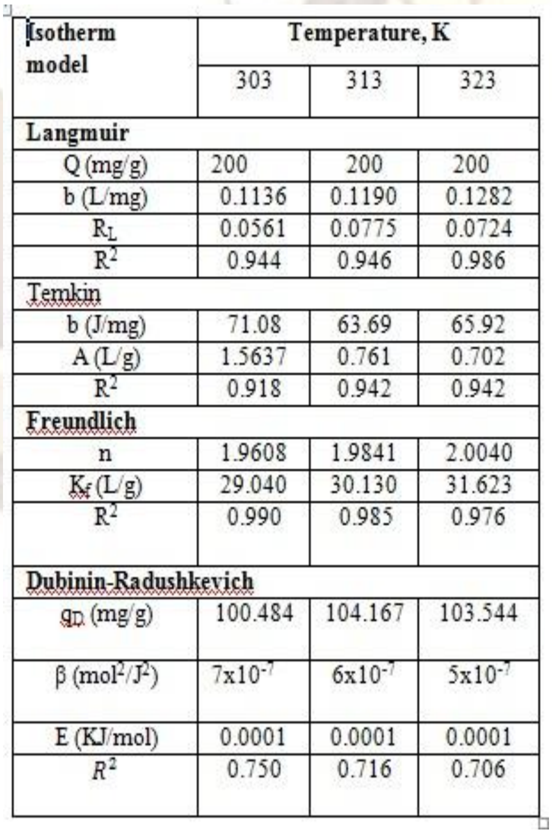
Isotherm model	**Temperature, K**		
	303	313	323
Langmuir			
Q (mg/g)	250	250	200
b (L/mg)	0.00468	0.00497	0.00658
R_L	0.6812	0.6680	0.6031
R^2	0.974	0.970	0.962
Temkin			
b (J/mg)	80.90	83.62	87.08
A (L/g)	0.120	0.127	0.135
R^2	0.904	0.914	0.916
Freundlich			
n	1.5900	1.2484	1.4925
K_f (L/g)	3.945	2.472	3.3729
R^2	0.994	0.965	0.997
Dubinin-Radushkevich			
q_D (mg/g)	66.089	65.957	66.820
β (mol^2/J^2)	$3x10^{-5}$	$2x10^{-5}$	$2x10^{-5}$
E (KJ/mol)	0.0013	0.0016	0.0016
R^2	0.680	0.679	0.683

Table 5: Calculated isotherm parameters for the adsorption of Pb^{2+} on OPF



Isotherm model	**Temperature, K**		
	303	313	323
Langmuir			
Q (mg/g)	250	250	250
b (L/mg)	0.00400	0.00420	0.00442
R_L	0.7143	0.7042	0.6934
R^2	0.952	0.957	0.940
Temkin			
b (J/mg)	76.49	81.01	83.42
A (L/g)	0.089	0.098	0.105
R^2	0.923	0.916	0.912
Freundlich			
n	1.4577	1.4793	1.5267
K_f (L/g)	2.838	3.034	3.412
R^2	0.999	0.999	0.998
Dubinin-Radushkevich			
q_D (mg/g)	66.620	70.881	77.634
β (mol^2/J^2)	$5x10^{-5}$	$2x10^{-5}$	$3x10^{-5}$
E (KJ/mol)	0.001	0.0016	0.0013
R^2	0.717	0.583	0.569

Table 6: Calculated isotherm parameters for the adsorption of Pb^{2+} on OPS



Isotherm model	**Temperature, K**		
	303	313	323
Langmuir			
Q (mg/g)	200	200	200
b (L/mg)	0.1136	0.1190	0.1282
R_L	0.0561	0.0775	0.0724
R^2	0.944	0.946	0.986
Temkin			
b (J/mg)	71.08	63.69	65.92
A (L/g)	1.5637	0.761	0.702
R^2	0.918	0.942	0.942
Freundlich			
n	1.9608	1.9841	2.0040
K_f (L/g)	29.040	30.130	31.623
R^2	0.990	0.985	0.976
Dubinin-Radushkevich			
q_D (mg/g)	100.484	104.167	103.544
β (mol^2/J^2)	$7x10^{-7}$	$6x10^{-7}$	$5x10^{-7}$
E (KJ/mol)	0.0001	0.0001	0.0001
R^2	0.750	0.716	0.706

CONCLUSION

The potential of NPN, PPN, EFB, OPF and OPS as low-cost adsorbents for the removal of Pb^{2+} from aqueous solutions was established. The study shows that these waste and available agricultural materials can be used as adsorbents for the removal of Pb^{2+} from industrial wastewater. It can be concluded that NPN and OPS are the most efficient for removing Pb^{2+} from aqueous solutions The ranking of adsorbents for Pb^{2+} adsorption showed this order: OPS>NPN>PPN>EFB>OPF. The amount of Pb^{2+} adsorbed was found to vary with adsorbent dosage, pH, initial ion concentration, particle size, and contact time. Isotherms for the adsorption of lead on the adsorbents were developed and the equilibrium data fitted well to the Freundlich, Langmuir and Temkin models. The equilibrium data was best described by Freundlich model.

REFERENCE

1. Roque-Marlberbe R. M. A., Adsorption and Diffusion in Nonporous Materials, CRS Press, USA, 2007,39-255
2. Ruthven, D. M., Encyclopedia of Separation Technology, vol.1, A Wiley-Interscience Publication, USA, 1984, 72-123.
3. Patrick J. W., Porosity in Carbon: Characterization and Application, 1st edition. Edward Arnold Publishers, London, 1995, 3-252.
4. Bansal R. C. and Goyal M., Activated Carbon Adsorption, CRC Press, 1st edition, USA, 2005,1-5.
5. Castro J, Bonelli P, Cerrella E. and Cukierman A., Phosphoric acid activation of agricultural residues and bagasse from sugar cane: influence of the experimental conditions on adsorption characteristics of activated carbons, *Ind. Eng. Chem. Res; 39*, 2000, 4166-4170.
6. Qaiser S, Saleem A. R., and Ahmed M. M., Heavy metal uptake by agro based waste materials. *Environmental Biotechnol*. *10(3)*, 2007, 1-8.
7. Gupta, V. K. and Ali, I. Removal of lead and chromium from wastewater using bagasse fly ash-sugar industry waste. J. Colloid Interface Sci., *271(2)*, 2004, 321.
8. Ahmad A.A, Hameed B.H. and Aziz N., Adsorption of direct dye on palm ash: kinetic and equilibrium modeling, *Journal of Hazardous Materials*, *094*, 2006, 1-10.
9. American Society for Testing and Materials Annual Book of ASTM Standard, 15.01, Refractories, Carbon and Graphic Products; activated Carbon, ASTM, Philadelphia, PA. (1996).
10. American Society of Testing and Materials Standard test methods for moisture in activated carbon. Philadelphia, PA: ASTM Committee on Standards (1991).
11. Ahmedna M, Johns M.M, Clarke, S. J, Marshall, W. E. and Rao, R. M., Potential of agricultural by-product-based activated carbons for use in raw sugar decolourisation, *Journal of the Science of Food and Agriculture*, 75, 1997, 117-124.
12. American Society for Testing and Materials. Standard test method for determination of iodine number of activated carbon. Philadelphia, PA: ASTM Committee on Standards (1986).
13. Al-Qodah Z. and Shawabkah R., Production and characterization of granular activated carbon from activated sludge, *Braz. J. Chem. Eng*, *26(1)*, 2009, 6.
14. Alzaydian A. S., Adsorption of methylene blue from aqueous solution onto a low – cost natural Jordanian Tripoli, *Am. J. Applied Sci*., 6(6), 2009, 1047-1058.
15. Valix M, Cheung W. H. and McKay G., Preparation of activated carbon using low temperature carbonization and physical activation of high ash raw bagasse for acid dye adsorption, *Chemosphere*, *56*, 2004, 493-51.
16. Pendyal B, Johns M. M, Marshall W. E, Ahmedna M. and Rao, R. M., The effect of binders and agricultural by-products on physical and chemical properties of granular activated carbon. *Bioresour. Technol*., *68(3)*, 1999, 247-254.
17. Yenisoy-Karakas S, Aygua A, Gunes M. and Tahtasakal E., Physical and chemical characteristics of polymer-based spherical activated carbon and its ability to adsorb organics. *Carbon*, *42*, 2004, 422-484.
18. Abdulla, A. H, Kassim A, Zaninal Z, Hussien, M. Z, Kuang D, Ahmad F. and Nool, O.S., Preparation and characterization of activated carbon fromGelam wood bark (Melaleuca cajuputi), *Malaysian J. of Analytical Sci*., *7(1)*, 2001, 65-68.
19. Bulut Y. and Aydin H., A kinetic and thermodynamics study of methylene blue adsorption on wheat shells, *Desalination*, *194*, 2005, 259-267.

20. Karthikeyan S, Sivakumar P. and Palanisamy P. N., Novel activated carbons from agricultural wastes and their characteristics, *E – Journal of Chemistry*, *5*, 2008,409-426.

21. Gueu S, Yao B, Adouby K, and Ado, G. Heavy metals removal in aqueous solution by activated carbons prepared from coconut shell and seed shell of the palm tree. *Journal of Applied Sciences*, *6(13)*, 2006, 2789-2793.
22. Maheswari P, Venilamani N, Madhavakrishnan S, Shabudeen P. S, Venckatesh R, and Pattabhi S., Utilization of Sago waste as an adsorbent for the removal of Cu(II) ion from aqueous solution, *E – Journal of Chemistry*, *5(2)*, 2008,233-242.
23. Sekar M, Sakthi V. and Rengaraj S., Kinetics and equilibrium adsorption study of Lead (II) onto activated carbon prepared from coconut shell, *Journal of Colloid and Interface Science*, *279(2)*, 2004, 307-313.

24. Demirbas E, Kobya M, Senturk E. and Ozkan T., Adsorption kinetics for the removal of chromium (VI) from aqueous solutions on the activated carbons prepared from agricultural wastes. *Water SA*, *30(4)*, 2004, 533-539.
25. Liu Y, Xiao D. and Li H., Kinetics and thermodynamics of Lead (II) adsorption on vermiculite, *Separation Science and Technology*, *42*, 2007, 185-202.
26. Sivakumar P. and Palanisamy P. N., Adsorption studies of basic Red 29 by a non-conventional activated carbon prepared from Euphorbia antiquorum L, *International Journal of Chem. Tec. Research*, *1 (3)*, 2009, 502-510.

27. Goswami, S. and Ghosh, U. C., Studies on adsorption behaviour of Cr(VI) onto synthetic hydrous stannic oxide. *Water SA*, *31(4)*, 2005, 597-602.

28. Aksu Z, and Tezer S., Equilibrium and kinetic modelling of bisorption of remazol black B by Rhizopus arrhizus in a batch system: effect of temperature, *Process Biochemistry*, *36*, 2000, 431-439

29. Lin S.H. and Juang R. S., Heavy metal removal from water by sorption using surfactant-modified montmorillonite. *J. Hazard. Mater*., 92, 2002, 315-326.

30. Choy K. K. H, Mckay G. and Porter J. F., Sorption of acid dyes from effluents using activated carbon. *Resources, Conservation and Recycling*, *27*, 1999, 57-71.

31. Sarin V, Singh T. S. and Pant, K. K., Thermodynamic and breakthrough column studies for the selective sorption of chromium from industrial effluent on activated eucalyptus bark. *Bioresourse Technol*., *97*, 2006, 1986-1993.