# *Comparative Studies of Adsorption of Heavy Metals from Wastewater by Blighia Sapida Seeds, Pods and Their Blends*

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## Abstract

This study was carried out to compare the adsorption capacities of modified activated carbons prepared from *Blighia sapida* seed, pod and their blends in ratio blend (1:1), blend (1:3) and blend (3:1) for the removal of heavy metals (Pb, Cu, Zn & Fe) from wastewater. The adsorption studies of heavy metals from wastewater revealed lead (Pb) to be below detectable limit, while Cu (2.14 mg/L), Fe (1.80 mg/L) and Zn (2.82 mg/L) were estimated to be above WHO limits. Batch adsorption experiments were investigated by varying contact time, pH, dosage and temperature. The optimum contact time required for adsorption was 40 minutes for Cu, Zn and Fe. Adsorption data were fitted in to pseudo-first-order and pseudo-second-order kinetics model and the experimental values were fitted well for pseudo-second-order kinetics due to correlation coefficient, $R^2$ values ($\geq$ 0.9) which showed adsorption rate of Fe greater than Cu and Zn. Thermodynamic studies shows the positive value of $\Delta G°$ which is non-spontaneous for the adsorption of zinc onto the blend (1:1). This study showed that activated carbon from *Blighia sapida* could be used as low cost effective adsorbents in the treatment of industrial effluent.

**Keywords:** *Heavy metals; Wastewater; Biosorption; Kinetics; Thermodynamics.*

## Introduction

Heavy metals are natural consistent of the earth crust, but indiscriminate human activities have drastically disrupt their geochemical and biochemical balance. The world has faced increase in degradation of vital natural resources due to heavy metal pollution which has affected environmental management and sustainable development.[1] Potentially toxic pollutants endanger public health by being incorporated in the food chain, or being released into overlying waters which serve as drinking water supplies. Prolonged exposure to heavy metals such as copper, lead,

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nickel and cadmium can lead to serious health problems such as severe dysfunction in the renal, reproductive and central nervous system and numerous diseases and disorder even at low concentration[2].

Rapid industrialization has led to a substantial increase in the use and release of heavy metals into the ecosystem over the past few decades.[3] Automobile waste disposed indiscriminately has lead to substantial alteration in the chemical composition and pH of soil and water. The impact of these waste have shown a major effect on human health, plant growth and microbial population[4].

Several methods have been devised for the treatment and removal of heavy metal from wastewater. These methods include chemical precipitation, reverse osmosis, solvent extraction, ion exchange, phyto-extraction, oxidation-reduction, nanofiltration and biosorption[5]. These methods however, are either insufficient or expensive especially when the concentration is low, in the range of 1-100mg/L.[6]. The disadvantages of these technologies include high cost, sensitive operating conditions and production of toxic sludge.

In recent years, the need for safe and economical methods for the elimination of heavy metals from contaminated waters has necessitated research interest towards the production of low cost alternatives to commercially available biosorbent. Biosorption method has become a suitable method for wastewater treatment because of its simplicity, eco-friendly nature and cost effectiveness[7]. Some low cost biomass such as akee apple seeds, rice husk, apricot seeds, banana, orange, apple peels, sugar cane, cotton seeds, coconut shell, maize cobs and fistula leaves have been suggested as potential biosorbent for the removal of heavy metals from waste water due to their high carbon content[8]. Most of these biomass are used in form of granular or powdered activated carbon which have been employed as adsorbents for the removal of both heavy metals and organic pollutants from contaminated water.

*Blighia sapida* otherwise known as Akee Apple considered in this study is an evergreen dense crown tree of about 25 m having leathery red and yellow fruits belongs to family *Sapindaceae* widely distributed in tropical western African countries such as Nigeria, Mali, Ghana, Guinea and Benin. It is important to note that large quantities of *B.sapida* pods and seeds are being generated annually without proper disposal system which results in environmental pollution. This low value waste produced in huge quantities can be converted into adsorbent that will be utilized to remove toxic metals from industrial effluents. This would be beneficial to the environment at large and also save the cost of purchasing highly expensive activated charcoal. The study therefore is aimed at investigating the adsorption potential of chemically modified activated carbon produced from *Blighia sapida* pods, seeds and their different blend ratios as adsorbents in the removal of Pb, Cu, Fe and Zn from

wastewater obtained from mechanic site Keteran Gwari, Minna for better comparison and potential exploitation.

## Materials and Methods

### *Biosorbents Collection*

*Blighia sapida* (ripe) were randomly collected at different location within Bida metropolis, Niger state, Nigeria. A composite sample was made from where the representative samples were chosen for comparative sorption studies.

### *Biosorbent Pretreatment*

The seeds and pods of the representative sample of *Blighia sapida* were separated, rinsed properly with distilled water to remove sand and debris, after which they were sundried. The dried seeds and pods were ground and sieved through 250 µm mesh screen to obtain fine powder. The fine screened adsorbents obtained were charred in a muffle furnace at 600 $^{o}$C for 10 minutes. The carbonized samples produced were treated with activating agent ($HNO_3$). Modification process was carried out by soaking carbonized samples with 1M $HNO_3$ acid solution for 30 minutes. The acid solution was filtered off and the carbonized sample was rinsed severally with distilled water to remove residual acid. The prepared samples were allowed to dry in an oven at 105$^{o}$C. The acid modified carbon of the seeds, pods and the blend ratios at (1:1, 1:3 and 3:1) produced were kept separately in a polyethylene container and labelled for comparative sorption studies. The percentage yield from each prepared adsorbent was calculated using the equation 1**:**

$$\%\, Yield = \frac{mass\ of\ biochar}{mass\ of\ biomass} \times 100 \quad \text{.....(1)}$$

### *Wastewater collection*

The study area chosen was the mechanic village at Keteran Gwari, Minna, Nigeria. This site represents a peri-urban centre with mechanic workshops and dumpsites. Samples of water were collected from the stream in a good quality screw-capped high density pre- sterilized polypropylene container of 5-litre capacity and labelled properly.

### *Wastewater Preservation and Digestion*

The wastewater sample was preserved by adding concentrated $HNO_3$. This was done to maintain the oxidation state of various metal ions in solution[9]. The water sample was refrigerated at 4$^{o}$C prior to digestion. The preserved water sample was digested using a procedure modified by Opaluwa *et al*[10].

*Physicochemical Properties of Wastewater*

The wastewater sample was analysed for some physical and chemical parameters such as pH, conductivity, temperature, chemical oxygen demand, total hardness and chloride content in accordance with the standard methods.[11] pH and temperature were measured at sampling site.

*Heavy Metal Analysis*

The selected heavy metal analysed were Pb, Cu, Zn and Fe. Heavy metals analysis was carried out on the wastewater sample using Atomic absorption spectrophotometer (AAS) (Perkin Elmer; Analyst 200)

*Batch Adsorption Experiment*

Batch adsorption experiments were conducted by contacting a known weight of the sample with 40cm$^3$ of wastewater solution under different conditions. Studies were carried to determine the effect of pH, dosage, temperature and contact time on adsorption rate.

The percentage removal of heavy metal from solution was calculated by the equation 2:

$$Adsorption\ (\%) = \frac{(C_i - C_f)}{C_i} \times 100 \quad \text{(2)}$$

The adsorption capacity, $q_e$, was calculated as:

$$q_e = \frac{(C_o - C_e)V}{m} \quad \text{(3)}$$

Where $C_o$ and $C_e$ are the initial and equilibrium adsorbate concentrations in solution (mg/L), respectively, *V* is a known volume of wastewater (L), and *m* is a known mass of dry adsorbent (g).

## *Adsorption Kinetics*

For kinetic studies, masses of adsorbents were contacted with the waste water. At respective contact time, the solution was filtered and analysed for the final concentrations.

Several adsorption kinetics models have been developed to understand the adsorption kinetics and rate limiting step. Two kinetic models were considered to investigate the mechanism of adsorption, as follows:

Lagergren proposed a pseudo-first order kinetic model and is expressed as[38, 39].

$$\ln(q_e - q_t) = \ln q_e - k_1 t \quad \text{(4)}$$

Where $q_e$ is the amount of metal sorbed (mg/g) at time *t* (min), *qe* is the amount of metal sorbed at equilibrium (mg/g), $k_1$ is the equilibrium rate constant of pseudo-first order adsorption (min$^{-1}$). This model was successfully applied to describe the kinetics of many adsorption systems.

The pseudo-second order kinectic model and is expressed as:

$$\frac{t}{q_t} = \frac{1}{k_2 q_e^2} + \frac{t}{q_e} \quad \text{..... (5)}$$

Where $k_2$ is the pseudo-second order rate constant of adsorption. The applicability of the above two models can be examined by each linear plot of $\ln(q_e - q_t)$ against $t$, and $(t/q_t)$ against $t$, respectively[40, 41].

### *Thermodynamics Studies*

The thermodynamic parameters of the adsorption process, i.e. the standard Gibbs free energy $\Delta G°$ (kJ/mol), standard enthalpy $\Delta H°$ (kJ/mol) and entropy $\Delta S°$ (J/mol K) were calculated from the Vant Hoff equation using the equilibrium adsorption data from the effect of temperature.

$$\Delta G^\circ = -RT\ln K$$

$$\ln K = -\frac{\Delta H^\circ}{RT} + \frac{\Delta S^\circ}{R} \quad \text{..... (6)}$$

Where the slope and intercept of the plot of $\ln K$ versus $1/T$ were used to determine the $\Delta H°$ and $\Delta S°$. $R$ is the gas constants (8.314 J/mol K) and $T$(K) is the absolute temperature.

## Results and Discussion

### *Physico-chemical Properties of Wastewater*

The results of physical and chemical properties of wastewater from keteran Gwari mechanic site Minna, Niger State, Nigeria are presented in Table 1. The wastewater sample temperature and pH values (30$^o$C and 6.62) respectively were within WHO standard limit which also favours survival metabolism and physiology of aquatic organisms. Temperature over 30 $^o$C and low pH can cause regression in growth and decay in plants[12]. The pH of water body influences the concentration of many metals by altering their availability and toxicity[13]. The total hardness of the wastewater sample observed was 340mg/L. Water with hardness greater than 300 mg/L is considered very hard[14]. The COD value (60.6 mg/l) observed was very high indicating high level of toxic waste in the water. This could be as a result of seepage of waste generated by mechanic activities from soil into the water body. Alkalinity value was 260 mg/L. Water with an alkalinity below about 100 mg/L as $CaCO_3$, is poorly buffered and pH sensitive. This could be harmful to the plants and animals that live there[15]. Moderately alkaline water less than (350 mg/L) in combination with hardness forms a layer of calcium or magnesium carbonate that tends to inhibit corrosion of metal piping[16].

**Table (1):** Physicochemical Analysis of Wastewater from Ketrean Gwari Mechanic site, Minna, Niger State, Nigeria.

| Parameters | Wastewater sample | WHO |
|---|---|---|
| Temperature | 30 | |
| pH | 6.62 | 6.5- 9.5 |
| Total Hardness (as CaCO ) mg/L | 340 | 500 |
| Alkalinity (methyl orange) mg/L | 260 | |
| COD (mg/L) | 60.6 | |
| TDS (mg/L) | 463.1 | 500- 1000 |
| Conductivity µs/cm | 768 | |
| Chloride (mg/L) | 16.8 | 250 |

WHO (World Health Organization, 2011)

### *Heavy Metals Analysis of Wastewater*

The concentrations (mg/l) of selected heavy metals (Pb, Cu, Zn and Fe) in wastewater from Keteran Gwari Mechanic site, Minna, Niger State, Nigeria are shown in Table 2. The trend of abundance of these metals in wastewater follows this sequence: Zn>Cu>Fe>Pb. The concentration of Pb was below detectable limit. Zn concentration (2.82 mg/L) was below WHO permissible limit while Cu (2.14 mg/L) and Fe (1.2 mg/L) were above WHO permissible limit. High level of Cu and Fe can be attributed to abundance of Fe and Cu containing waste in the environment from mechanic activities[17]. This is similar to findings of Usman *et al*[18].

**Table (2)**: Heavy Metals Analysis of the Wastewater Sample

| S/N | Heavy metal | Waste water(mg/L) | WHO (mg/L) |
|---|---|---|---|
| 1 | Zn | 2.82 | 3 |
| 2 | Cu | 2.14 | 1 |
| 3 | Fe | 1.2 | 0.01 |
| 4 | Pb | 0.00 | 0.3 |

WHO[15].

### *Batch Adsorption Experiments results*

### *Effect of contact time*

Figure 1a-c shows the effect of contact time on Fe, Zn and Cu ion uptake by the selected adsorbents. This was achieved by varying the contact time from 20 to 100 minutes in separate experiment runs. Equilibrium contact time and maximum adsorption strength was attained within 40 minutes of shaking for all the metal ions, the order are; Fe (seed>blend1:3>blend3:1>blend1:1>pod); Cu (blend1:3>seed>blend3:1>

blend1:1>pods) and Zn (blend1:3> blend3:1>seed>blend1:1>pod). The percentage removal rate of (Fe> Zn>Cu) gradually decreased with increase in contact time. Initially, the rate of the selected metals uptake were higher because all sites on the adsorbent were vacant and metal ion concentration were high, but decrease of sorption sites reduced the uptake rate. This could be as a result of formation of repulsive forces between the metal ions on the solid surface and phase of the adsorbent[19] Similar results were found in the study of Mousavi *et al*[20].

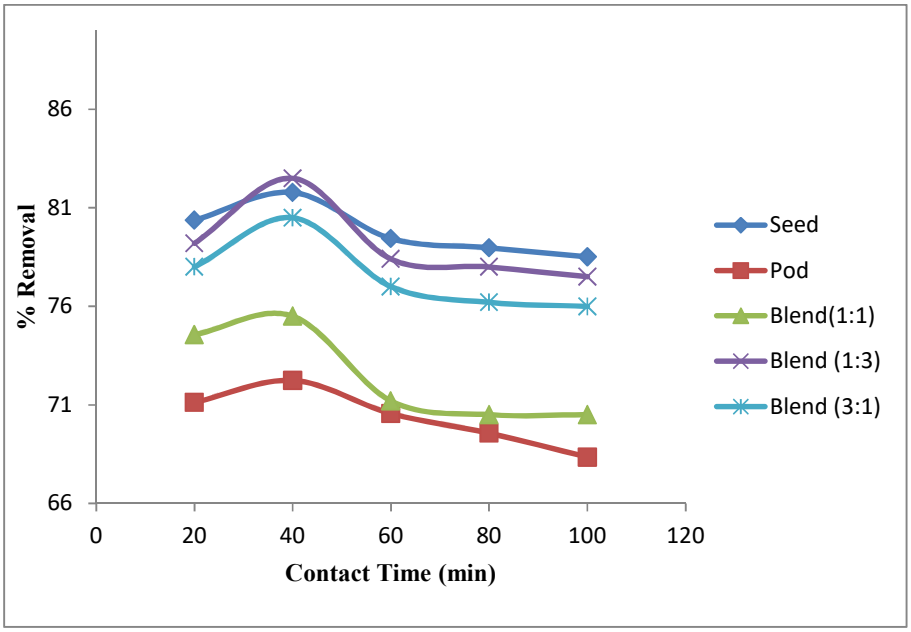



**Figure (1a)**: Effect of Contact Time on Adsorption of Copper

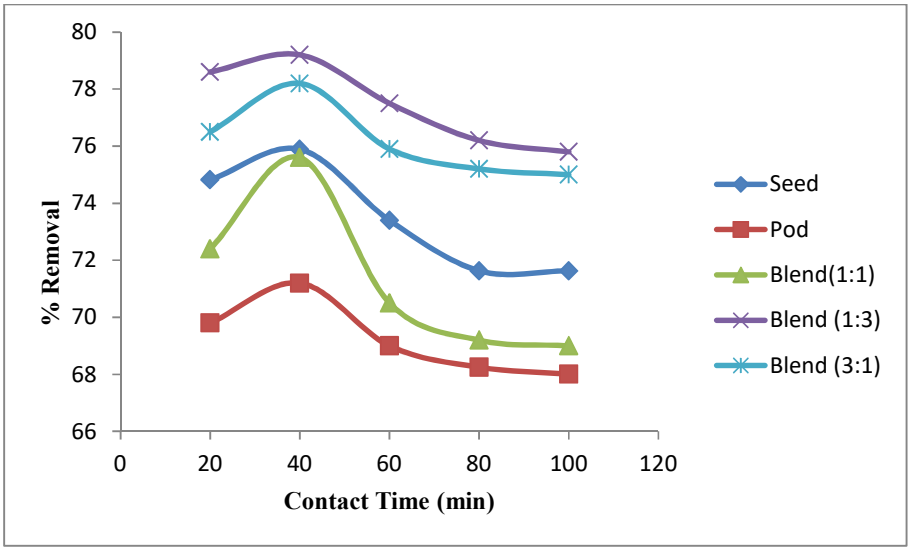



**Figure (1b):** Effect of Contact Time on Adsorption of Zinc

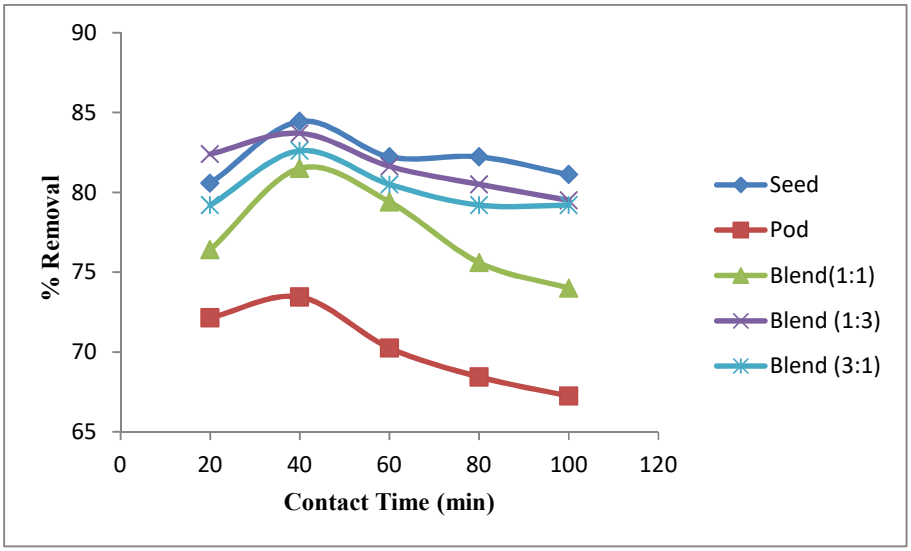



**Figure (1c):** Effect of Contact Time on Adsorption of Iron

*Effect of pH*

The effect of pH is one of the principal factors to be considered in heavy metal adsorption from wastewater on agricultural wastes. pH determines the surface charge of the adsorbent. The effect of pH on the biosorption of Cu, Zn, and Fe by modified activated carbon of seeds, pods and their different blend proportions (1:1, 1:3 &3:1) of *Blighia sapida* from wastewater is shown in Figure 2a-c. The percentage metal ion removal increased rapidly with the increase in pH of the solution initially and the optimal pH was observed at pH 4 on different proportion of adsorbents and order of removal as; Zn (seed>blend1:1>blend1:3>blend3:1>pods) and Fe (blend1:1>seeds> blend1:3>blend3:1>pods) and pH 6 for Cu (pods>blend1:1>seed>blend1:3>blend3:1).

It was observed that further increase in pH causes a decrease in adsorption percentage. This might be due to the weakening of electrostatic force of attraction between the oppositely charged adsorbate and adsorbent which ultimately leads to the reduction in sorption capacity.[21] This is similar to what was reported by Mulu[22].

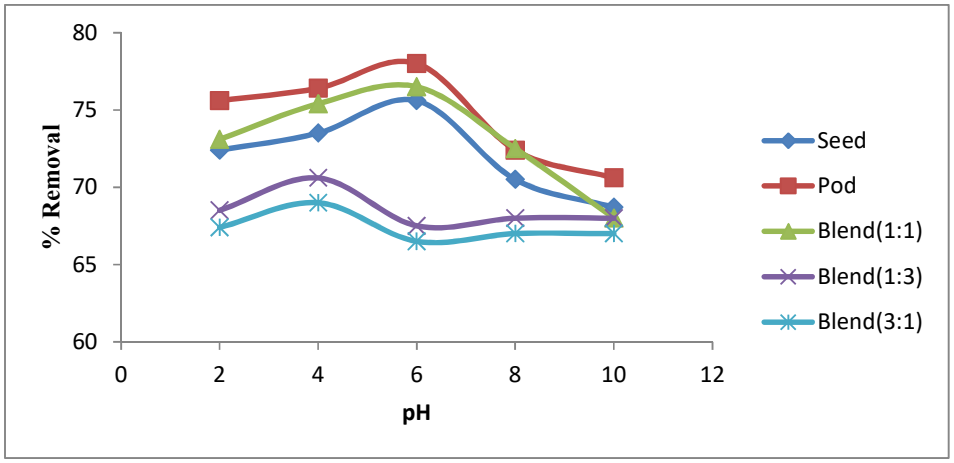



**Figure 2a:** Effect of pH on Adsorption of Copper

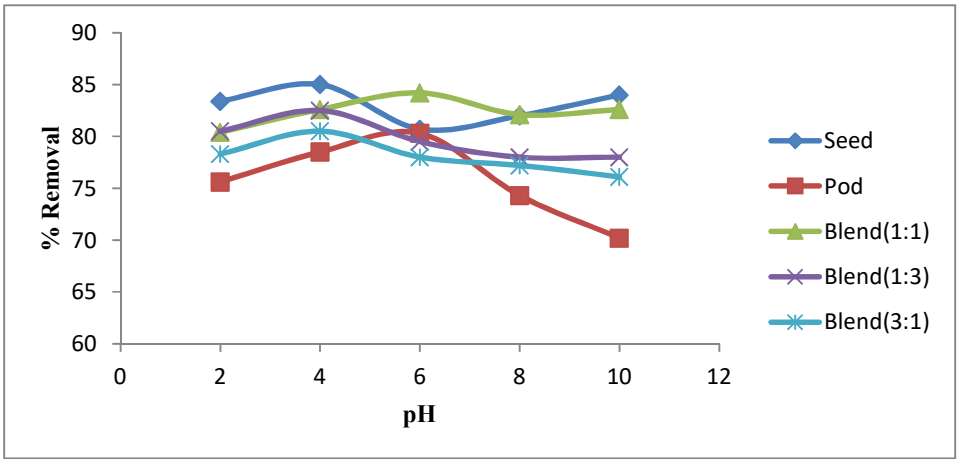



**Figure (2b):** Effect of pH on Adsorption of Zinc

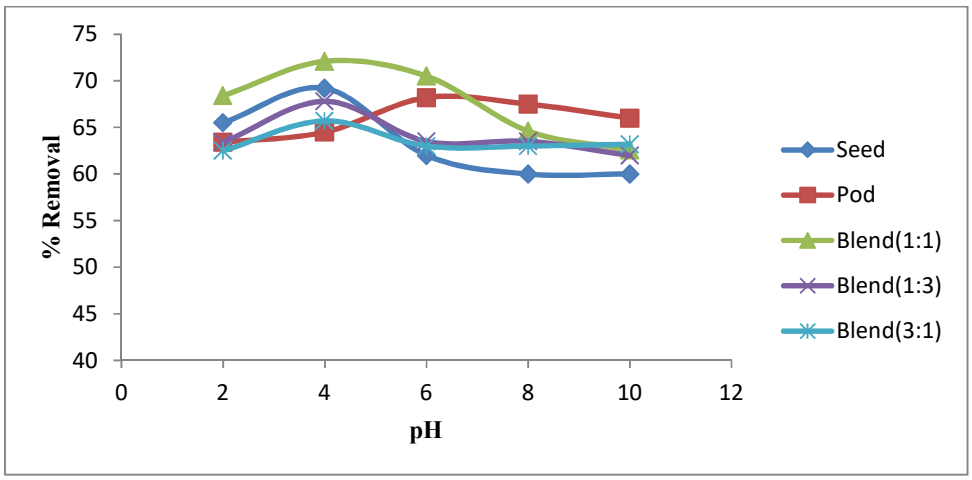



**Figure (2c):** Effect of pH on Adsorption of Iron

*Effect of Dosage*

The availability and accessibility of adsorption site is controlled by adsorbent dosage.[23] The result for adsorptive removals of Cu, Pb and Fe with respect to adsorbent dose are shown in Figure 3a-c. The percentage removal of metal ion increased with increasing weight of the adsorbent and the order of removal of the metals are (Fe>Zn>Cu). As adsorbent dosage increases, the adsorption increases due to more surfaces and functional groups available on adsorbent. The increase in available adsorption sites arising with the increase in surface area is an indication of increase conglomeration of the adsorbents[24,25]. These observations corresponded to the reports made by Mohanty *et al*. [26] and Mustapha *et al*[27].

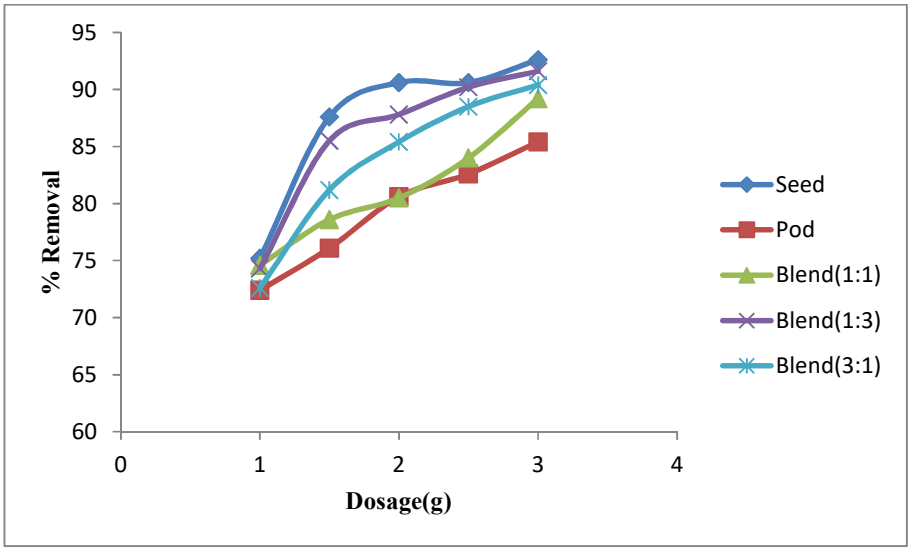



**Figure (3a):** Effect of Dosage on Adsorption of Copper

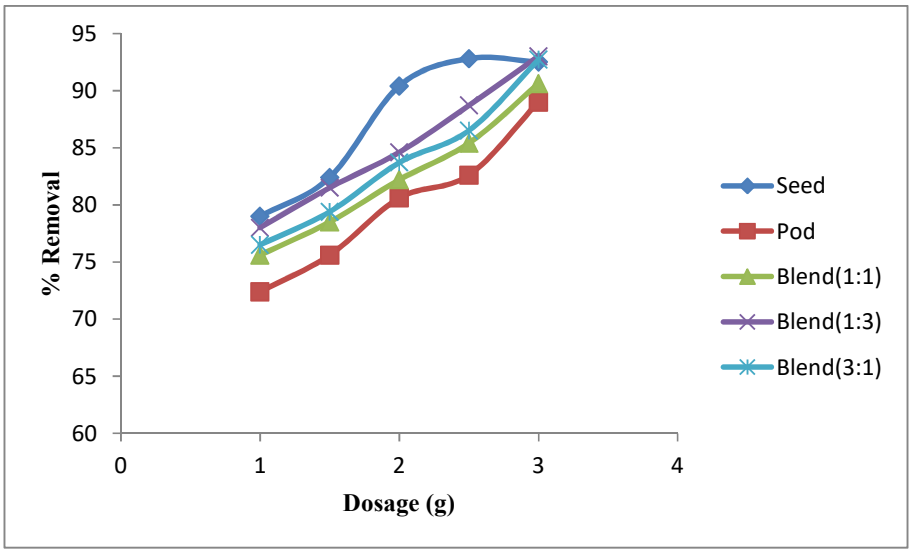



**Figure (3b):** Effect of Dosage on Adsorption of Zinc

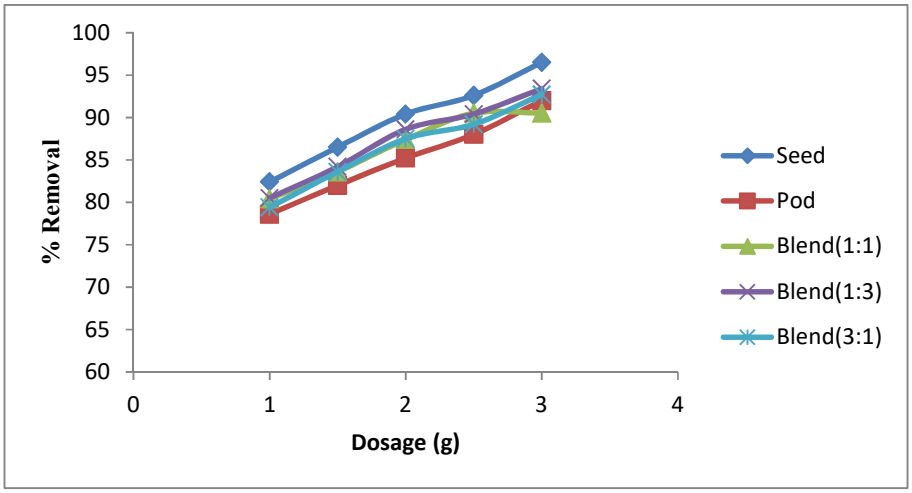



**Figure (3c):** Effect of Dosage on Adsorption of Iron

*Effect of Temperature*

The effect of temperature on adsorption of Cu, Zn and Fe is illustrated by the results depicted in Figure 4a-c. The experiments were conducted at different temperatures of 30, 40, 50, 60 and 70°C and results showed increase in percentage removal as temperature rises indicating better sorption at higher temperature. Biosorption of metal ions increases in the order Fe>Cu>Zn at temperature of 70°C. The order of adsorption capacity of all the adsorbent blend3:1>blend1:3> seed> pods>blend1:1 also increased with increase in temperature. This could be due to increase in kinetic energy of the sorbent particles and increase in the number of pores present and as a result, metal ion adsorbed easily unto the surface of the adsorbent.[28] The retarding specific or electrostatic interactions probably became weaker and the ions became smaller, because solvation is reduced[29,30]. This indicates that the adsorption reaction was endothermic in nature. This was similar to the findings of Shen and Duvnjak[31] and Mustapha *et al* [32].

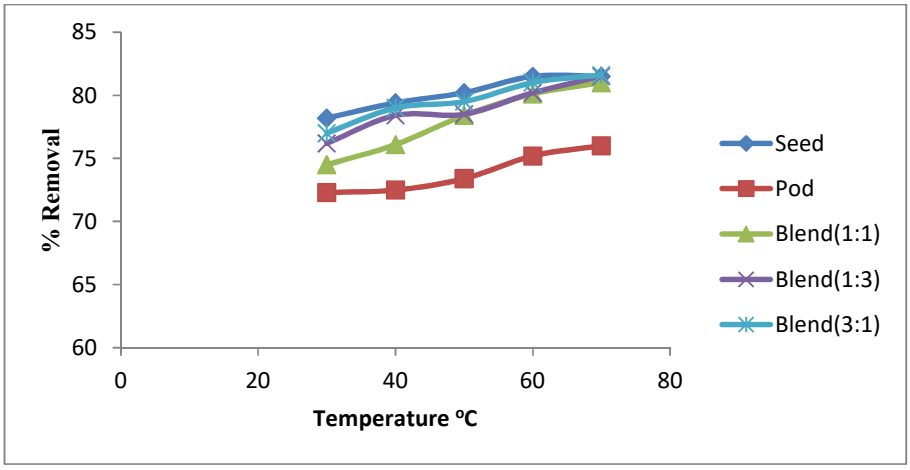



**Figure (4a):** Effect of Temperature on Adsorption of Copper

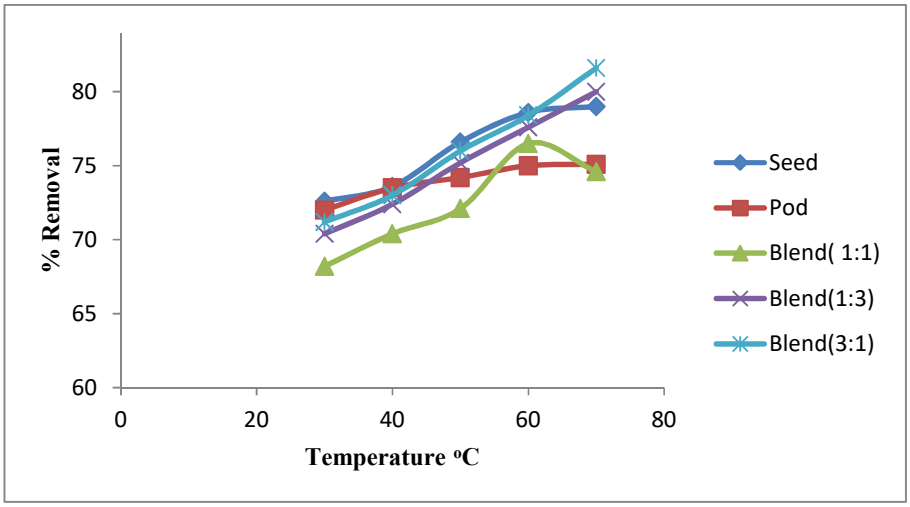



**Figure (4b):** Effect of Temperature on Adsorption of Zinc

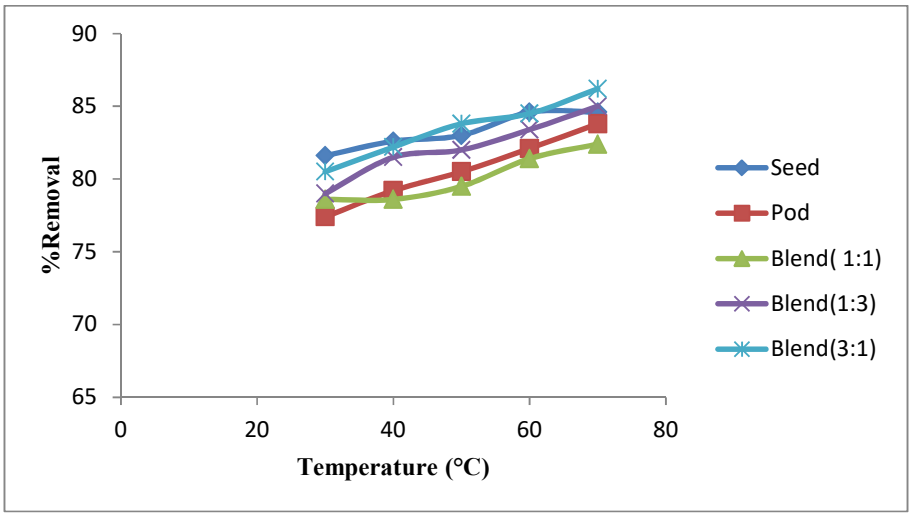



**Figure (4c):** Effect of Temperature on Adsorption of Iron

*Biosorption Kinectics*

The adsorption mechanisms of Cu, Fe and Zn onto modified seeds, pods and blend ratios of the adsorbent were analysed using pseudo-first order and pseudo-second order kinetic models. The plot of pseudo-first and pseudo-second are shown in Figure 5a-c and Figure 6a-c for the bisorption process of the metal ions by various adsorbent respectively. It was observed that the correlation coefficient $R^2$ values in the case of the pseudo second-order were higher than those for the pseudo-first-order and this confirms that the sorption process follows a pseudo-second-order mechanism.[33, 34] Better data fit with the pseudo-second-order model observed for all the metals implies chemisorption contribution to the metal uptake process as shown in Table 3. The rate of sorption of Zn was higher than Cu and Fe according to $R^2$ values. This shows that kinetics of metal biosorption by modified activated carbon of seeds and

pods of *Blighia sapida* were better described by pseudo second order kinetic model which is similar to the findings of Puello *et al*[35].

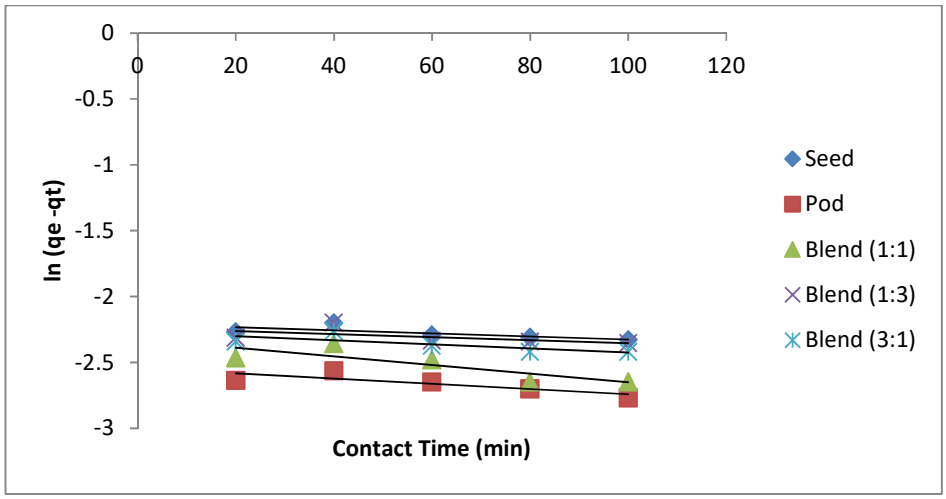



**Figure (5a):** Pseudo-first-order plot for adsorption of Copper

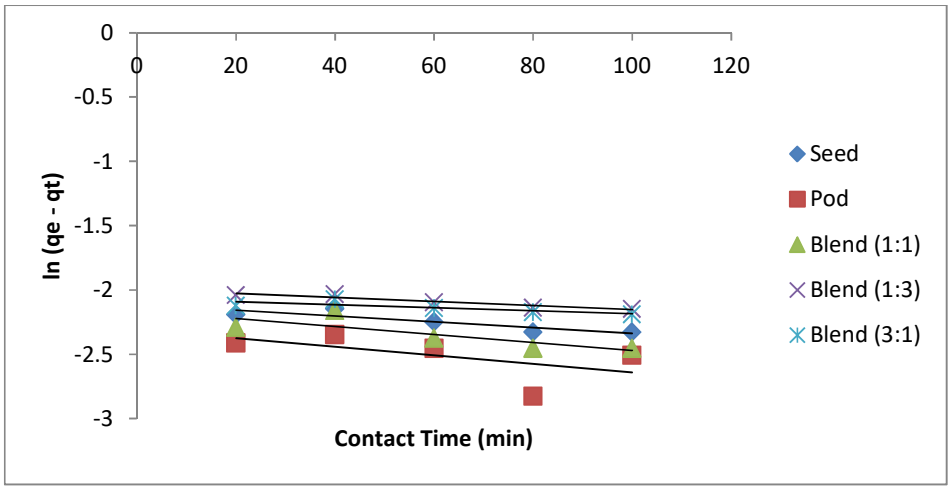



**Figure (5b):** Pseudo-first-order plot for adsorption of Zinc

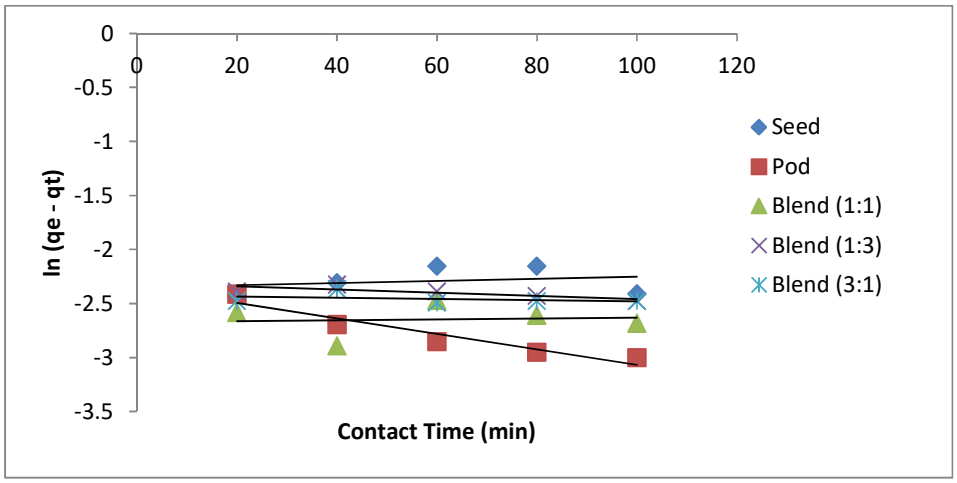



**Figure (5c):** Pseudo-first-order plot for adsorption of Iron

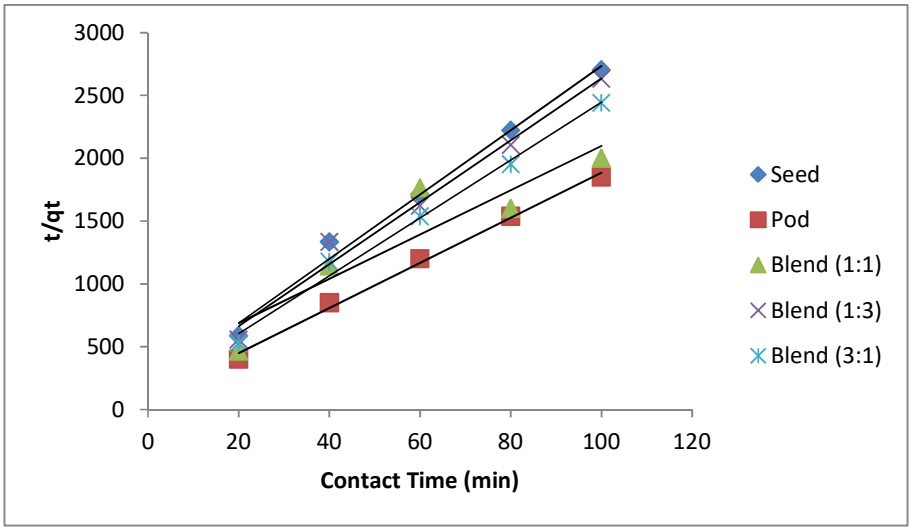



**Figure (6a):** Pseudo-second-order plot for Adsorption of Copper

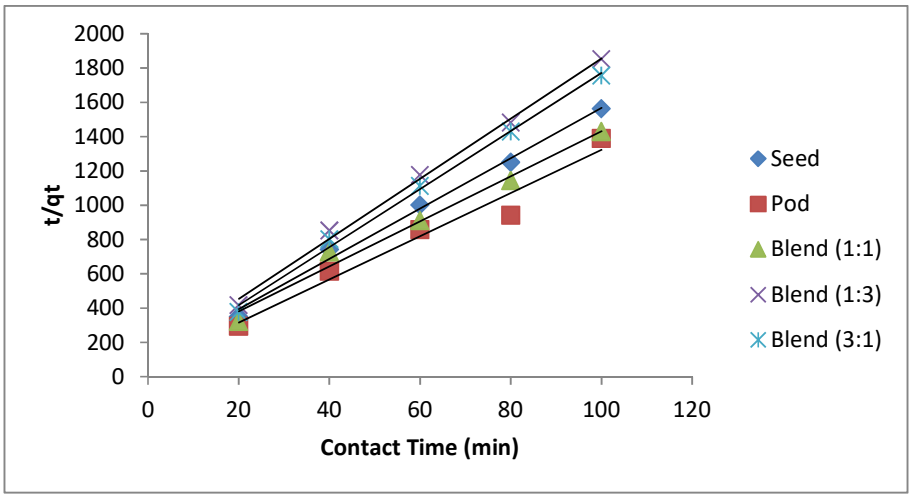



**Figure (6b):** Pseudo-second-order plot for Adsorption of Zinc

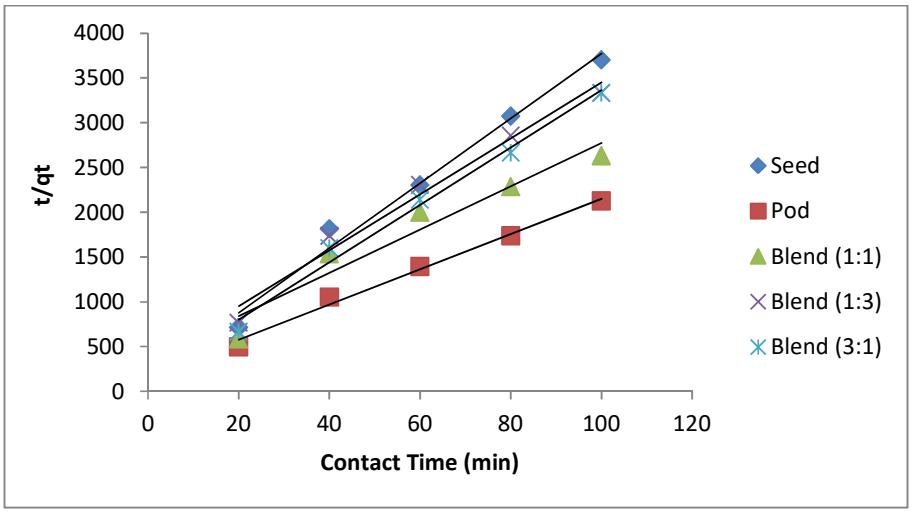



**Figure (6c):** Pseudo-second-order plot for Adsorption of Iron

**Table (3):** Pseudo-first and second order kinetics parameters

| Adsorbent | | pseudo-first order | | | pseudo-second order | | |
|---|---|---|---|---|---|---|---|
| | Heavy metal | $R^2$ | $k_1$ ($min^{-1}$) | $q_e$ ($mg.g^{-1}$) | $R^2$ | $q_e$ (calc) ($mg.g^{-1}$) | $k_2$($g\ mg^{-1}$ min) |
| Seed | Cu | 0.522 | $1\times10^{-3}$ | 0.110 | 0.989 | 0.039 | $6.575\times10^{2}$ |
| | Zn | 0.693 | $2\times10^{-3}$ | 0.123 | 0.985 | 0.068 | $2.163\times10^{2}$ |
| | Fe | 0.052 | $1\times10^{-3}$ | 0.096 | 0.994 | 0.028 | $1.276\times10^{3}$ |
| Pod | Cu | 0.677 | $3\times10^{-3}$ | 0.994 | 0.994 | 0.056 | $3.189\times10^{2}$ |
| | Zn | 0.320 | $3\times10^{-3}$ | 0.961 | 0.961 | 0.080 | $1.563\times10^{2}$ |
| | Fe | 0.857 | $3\times10^{-3}$ | 0.990 | 0.990 | 0.051 | $3.845\times10^{2}$ |
| Blend (1:1) | Cu | 0.685 | $2\times10^{-3}$ | 0.844 | 0.844 | 0.057 | $3.078\times10^{2}$ |
| | Zn | 0.619 | $3\times10^{-3}$ | 0.984 | 0.984 | 0.076 | $1.731\times10^{2}$ |
| | Fe | 0.325 | $2\times10^{-3}$ | 0.933 | 0.933 | 0.041 | $5.949\times10^{2}$ |
| Blend (1:3) | Cu | 0.320 | $1\times10^{-3}$ | 0.981 | 0.981 | 0.041 | $5.949\times10^{2}$ |
| | Zn | 0.897 | $1\times10^{-3}$ | 0.996 | 0.996 | 0.057 | $3.078\times10^{2}$ |
| | Fe | 0.635 | $1\times10^{-3}$ | 0.978 | 0.978 | 0.032 | $9.766\times10^{2}$ |
| Blend (3:1) | Cu | 0.564 | $1\times10^{-3}$ | 0.990 | 0.990 | 0.044 | $5.165\times10^{2}$ |
| | Zn | 0.667 | $1\times10^{-3}$ | 0.996 | 0.990 | 0.059 | $2.873\times10^{2}$ |
| | Fe | 0.129 | $1\times10^{-3}$ | 0.987 | 0.987 | 0.031 | $1.041\times10^{3}$ |

*Thermodynamic Studies*

Thermodynamic studies were carried out to verify the mechanism and feasibility of Cu, Fe and Zn biosorption on modified activated carbon produced from seeds and pods of *Blighia sapida.* The three parameters employed for the test were enthalpy change (∆H°), entropy change (∆S°) and the change of Gibbs free energy (∆G°). The plots and thermodynamic parameters were shown in Figure 7a-c and Table 4 respectively. The positive values of change in enthalpy (∆H°) indicated that the adsorption reaction was endothermic and has strong affinity of the adsorbents. The process of adsorption increases with the increase in temperature. The positive values of change in entropy (∆S°) reflected the affinity of the adsorbent for a particular metal ion and confirm increase in disorder and randomness at the solid solution interface of the metal ions with adsorbent[36]. The enhancement of adsorption rate of the chemically activated carbon at higher temperatures was attributed to the enlargement of pore size and activation of the adsorbent surface[37]. The positive values at different temperatures were due to the fact that the adsorption process is non-spontaneous. The value of ∆G° decreased with an increase in temperature which is an indication that

the spontaneous nature of the adsorption is inversely proportional to the temperature. This is in line with the finding of Mustapha *et al*[27].

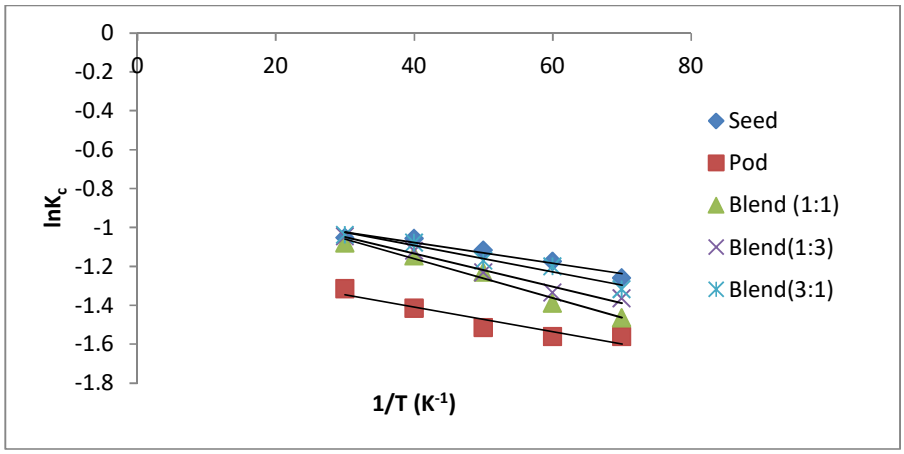



**Figure (7a):** Thermodynamic Plot for Adsorption of Copper

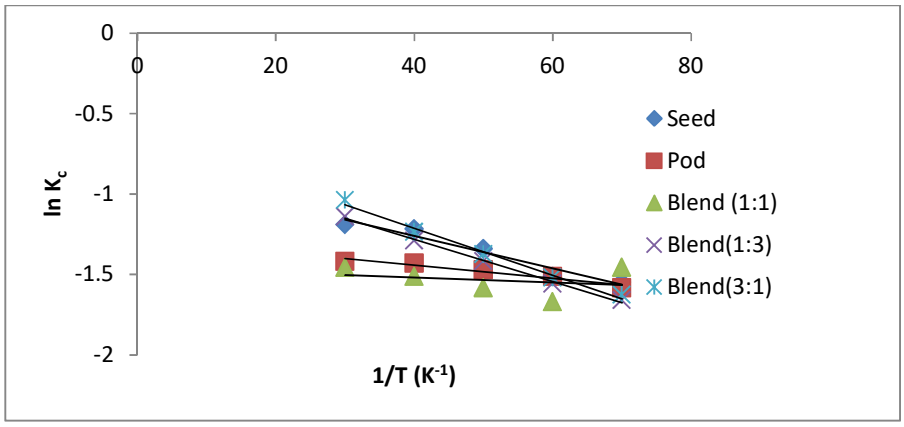



**Figure (7b):** Thermodynamic Plot for Adsorption of Zinc

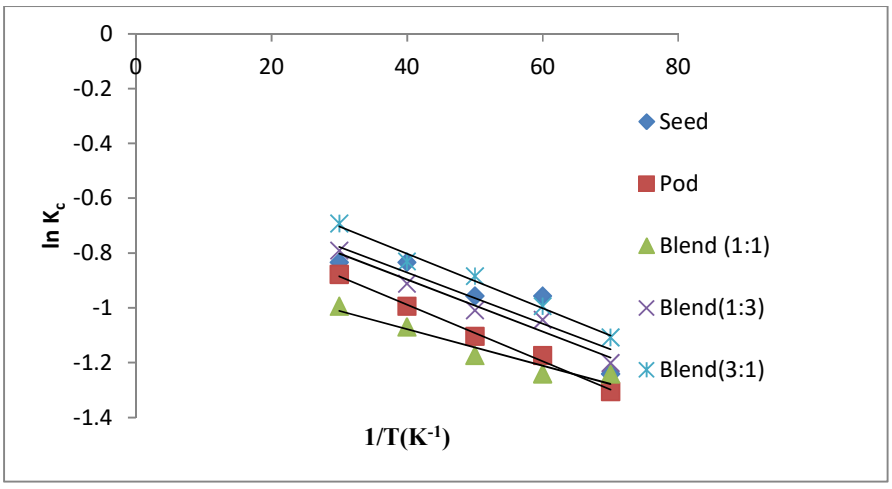



**Figure (7c):** Thermodynamic Plot for Adsorption of Iron

**Table 4:** Thermodynamic parameters

| Adsorbent | Metal | ΔHº (KJ/mol) | ΔSº ($Jmol^{-1}K^{-1}$) | ΔGº(KJ/mol) 303K | 313K | 323K | 333K | 343K | 353K |
|---|---|---|---|---|---|---|---|---|---|
| Seed | Cu | 4.340 | 4.041 | 3.116 | 3.075 | 3.035 | 2.994 | 2.954 | 2.914 |
| | Zn | 8.281 | 14.342 | 3.935 | 3.782 | 3.649 | 3.505 | 3.362 | 3.218 |
| | Fe | 7.782 | 16.104 | 2.903 | 2.742 | 2.580 | 2.419 | 2.258 | 2.087 |
| Pod | Cu | 4.465 | 1.513 | 4.007 | 3.991 | 3.976 | 3.961 | 3.946 | 3.931 |
| | Zn | 3.342 | 1.979 | 2.742 | 2.723 | 2.703 | 2.683 | 2.663 | 2.643 |
| | Fe | 8.630 | 17.684 | 3.272 | 3.095 | 2.918 | 2.741 | 2.564 | 2.388 |
| Blend | Cu | 8.314 | 15.273 | 3.686 | 3.534 | 3.381 | 3.228 | 3.075 | 2.923 |
| (1:1) | Zn | 1.305 | 8.705 | -1.330 | -1.420 | 1.507 | -1.594 | 1.681 | -1.768 |
| | Fe | 5.537 | 7.649 | 3.219 | 3.143 | 3.006 | 2.990 | 2.913 | 2.837 |
| Blend | Cu | 7.050 | 11.706 | 3.503 | 3.386 | 3.269 | 3.152 | 3.035 | 2.918 |
| (1:3) | Zn | 10.932 | 22,157 | 4.218 | 3.997 | 3.775 | 3.554 | 3.332 | 3.111 |
| | Fe | 7.907 | 16.262 | 2.980 | 2.817 | 2.654 | 2.492 | 2.329 | 2.167 |
| Blend | Cu | 5.679 | 7.948 | 3.271 | 3.191 | 3.112 | 3.032 | 2.953 | 2.873 |
| (3:1) | Zn | 12.222 | 26.372 | 4.171 | 3.905 | 3.639 | 3.374 | 3.108 | 2.842 |
| | Fe | 8.284 | 18.174 | 2.777 | 2.596 | 2.414 | 2.232 | 2.050 | 1.869 |

## Conclusions

The percentage removal of chemically activated carbon for the five samples increased with temperature which may be as a result of increase in the mobility of large metal ion with temperature. From the kinetic and thermodynamic analyses *B. sapida* (blend3:1) was found to be a better low cost biosorbent for metal ions from wastewater compared to the other adsorbents. The percentage removal increased with contact time and the regression correlation coefficient $R^2$ from adsorption data of Cu, Zn, and Fe on the biosorbent showed that pseudo-second-order expression better predicted the sorption kinetics of the metal ions onto the adsorbent. The sorption rate of Fe was greater than Cu and Zn. The low cost adsorbent could be a promising solution to the removal of heavy metals from industrial wastewater.

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