

Utilization of *Delonix regia* pods and leaves for the removal of Co (II) ions from synthetic wastewater

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ABSTRACT

Delonix regia pods and leaves were engaged as low cost adsorbent for the adsorption of Co (II) ions from aqueous solution. Batch adsorption of Co (II) ions was investigated as a function of some variables such as adsorbate solution pH; contact time of interaction; initial concentration of adsorbate; solution's ionic strength and adsorbent dosage with the aim of optimising the adsorption process. Experiments were carried out at temperature of $21 \pm 2^\circ\text{C}$; optimum pH of 4 and 6 for the pods and leaves respectively at a contact time of 30 minutes. Data from contact time study followed the pseudo-second order kinetic model while results obtained by varying the concentration of cobalt (II) ions between 1-200 ppm was modelled by the Langmuir and Freundlich isotherms. Both isotherms gave good fit for the adsorption of cobalt (II) ions unto the pods while the Freundlich isotherm provided better fit for *Delonix regia* leaves. The percentage adsorption recorded for adsorption unto the pods was 67.5% while 24.5% was recorded for sorption of cobalt (II) ions to the leaves. Result from this work showed that *Delonix regia* pods could be used to remove cobalt (II) ions from wastewater.

Keywords: *Delonix regia*, Cobalt (II) ions, Langmuir isotherm, Freundlich isotherm, Kinetic models

INTRODUCTION

One of the heavy metals present in the effluents of several industries is Cobalt due to its increase consumption in the manufacture of electronic devices, rechargeable battery electrodes and super alloys (Bernabé *et al.*, 2019). Like most heavy metals, cobalt is widely distributed in the environment and exposure to it could be through breathing air, eating food or drinking water contaminated with cobalt (Goyal and Agrawal, 2005). Skin contact with soil or water containing cobalt could also serve as an exposure route. Cobalt

is toxic to the human body even when the concentration ingested is small; it is referred to as an animal carcinogen capable of producing cancer at various sites of the body. Cobalt causes irritation to the skin and provoke allergic reaction in skin. It also causes irritation to the eyes and mucous membrane resulting in great discomfort in the nose and often causing perforation of the nasal septum; it also causes asthma-like allergy, damage to the heart, and damage to the thyroid and liver (Leyssens *et al.*, 2017 and Musapatika *et al.*, 2012).

In high concentration, cobalt may cause severe damage to human health (Hete *et al.*, 2012).

Chemical precipitation, solvent extraction, coagulation, ultra-filtration, reverse osmosis, membrane separation, biological systems, electrolytic processes ion exchange and adsorption are some of the conventional methods for removing heavy metals from industrial effluents (Abbas *et al.*, 2016 and Gode and Pehlivan, 2005) but adsorption processes, especially with activated carbon, is cheaper, easier to operate and more effective than other techniques (Abbas and Alalwan, 2019; Jabbari *et al.*, 2016 and Gupta *et al.*, 2003). The use of different adsorbents for removing heavy metals from industrial effluents is currently a research of great interest and in order to further reduce the cost of treating effluents and damage to the environment, research is geared towards the use of low cost adsorbents (Abourriche *et al.*, 2018; Babel and Kurniawan, 2003; Dias *et al.*, 2007; Memon *et al.*, 2009). Many agro-industrial productions by-products and agricultural by-products have been studied for potential use as inexpensive adsorbent (Ho, 2003). Many of these by-products are used directly or modified by heat or chemical treatment and reported as adsorbents in literature (Cochrane *et al.*, 2003; Abia *et al.*, 2002; Bailey *et al.*, 1999).

Adsorption of Co (II) ions in aqueous silica and rutile suspensions was investigated and reported by Kara *et al.*, (2003); the authors reported an increase in Co (II) ions adsorption with increase in adsorbate concentration and pH. Kim *et al.*, (2002) investigated the electro-sorption of Co (II) ions on a cellulose based activated carbon fibre KF-1500 after modification of the activated carbon surface in nitric acid and sodium hydroxide solutions and reported that the electro-sorption capacity of the activated carbon cellulose fibre increased when treated with both nitric acid and sodium hydroxide solutions. Bhatnagar *et al.*, (2010) worked on the adsorptive removal of cobalt from aqueous solution by utilizing lemon peel as adsorbent, and reported

that about 50% of cobalt (II) ions were removed within 2 hours of interaction and data were better fitted to the pseudo-second order kinetic model than the pseudo-first order model. Waghmare and Chaudhari (2015) investigated the removal of cobalt from waste water using *Moringa oleifera* bark and reported a maximum percentage efficiency of 85.33% at 360 minutes of contact.

Delonix regia is popularly grown in Africa and Hong Kong as a shade tree and for ornamental purpose. The tree has pods that can be as long as 60 cm in length and 5 cm wide, with a distinct bright green fern-like compound leaves. It belongs to the flowering plant family *Fabaceae* and commonly called the flame of the forest tree (Roy *et al.*, 2008). The pods and leaves of the tree have got no important economic use and thus, the outcome of its usage in this research would be of great benefit to most industries in the developing countries of the world, the adsorbent would serve as cheaper adsorbent for the removal of cobalt (II) ions from wastewater.

This research work is carried out to investigate the capacity of an agro-waste material, *Delonix regia* pods and leaves for the removal of cobalt (II) ions from aqueous solutions. The kinetics and equilibrium modelling of the process were also studied; desorption of adsorbed cobalt (II) ions from the adsorbent using various concentrations of nitric acid was considered.

MATERIALS AND METHODS

Collected dried leaves and pods of *Delonix regia* from Ekiti State University, Ado-Ekiti, Nigeria were employed for the sorption of Co (II) ion from solution. They were washed with deionized water, sun-dried and milled; then sieved through 250 μ m mesh nylon sieve and kept in air tight containers until required for use.

The powder obtained from the sieving process of the pods and leaves of *Delonix regia* were used as the adsorbents for this study while 1000 ppm stock solution of Co (II) was prepared from Cobalt

sulphate heptahydrate salt; from which the different concentrations needed were prepared by serial dilution. Adjustment of pH was done using 0.1 M nitric acid and sodium hydroxide. Different concentrations of sodium nitrate and nitric acid solutions were used for the experiment to investigate the effect of ionic strength of adsorbate solution on Co (II) ions adsorption and desorption of adsorbed ions from the adsorbent respectively. The milled adsorbents were sieved through 250 μ m mesh nylon sieve and kept in air-tight containers until needed.

From the fine powder, 0.5g was weighed into 50 ml tubes containing 20 ml of 100 ppm of the prepared Co^{2+} solution of pH 1.0 to 8.0. The suspensions were stirred at a speed of 18 rpm for 300 minutes and a temperature in the range of $21 \pm 2^\circ\text{C}$, after which they were centrifuged and analysed for the residual metal content using an inductively coupled plasma mass spectrometer (ICP-MS). Further experiments such as contact time study, adsorbent dose, ionic interference were carried out to optimize the adsorption process (Meena *et al.*, 2008).

Sorption kinetic was conducted by adding 0.5 g of *Delonix regia* pods to 20 ml of Co^{2+} solution and shaken for the interval of 0.5, 1, 3, 5, 10, 15, 30, 60, 90, 120, 180, 240, and 300 minutes. At the expiration of each time interval, the suspensions were centrifuged and analysed to determine the residual amount of Co^{2+} in the aqueous solutions. Desorption study was carried out with different concentrations (0, 0.05, 0.1, 0.5 and 1.0 M) of nitric acid. At the end of the adsorption experiments, the suspensions were centrifuged and the supernatant or liquid part was discarded. To the spent biomass were then added 20mls of the appropriate concentration of the desorbing agent (HNO_3) which were in designated plastic tubes for each concentration of desorbing agent for another 30 minutes. The process analysis is completed by centrifugation and metal analysis (Babalola *et al.*, 2020).

In all experiments conducted in this research, an initial concentration of 100 ppm of Co^{2+} and other experimental conditions of adsorbate solution pH of 4 and 6 for the pods and leaves respectively, adsorbate volume of 20 ml, 0.5g adsorbent dose, agitation rate of 18 rpm for 30 minutes contact time and temperature in the range of $21 \pm 2^\circ\text{C}$ were used with the exception of isotherm modelling experiment where concentrations ranging from (1, 5, 10, 20, 50, 100, and 200 ppm) were used (Aiyesanmi *et al.*, 2013). At the end of each experiment, an aliquot was withdrawn and diluted with 0.1 M HNO_3 before analysis for residual metal content.

The X Series Model of the ICP-MS was employed to determine the concentration of unadsorbed or residual Co (II) ions in the sorption medium, average results from the triplicate samples were reported after making correction for experimental blanks. The percentage adsorption (E) can be calculated using Equation 1 while the amount of Co (II) ions adsorbed or uptake by the adsorbent Q_e (mg/g) was calculated from Equation 2.

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

$$Q_e = (C_i - C_e) V / m \quad (2)$$

where C_i and C_e are the initial and equilibrium liquid-phase concentrations of Co (II) ions, respectively (ppm); V is the volume (L) and m is the mass of the adsorbent (g)

RESULT AND DISCUSSION

Study of the effect of pH on adsorption

The pH value of the adsorbate solution is a factor to consider in adsorption experiments as pH generally affects the solubility of ions in aqueous solutions and also have effect on the functional groups on the surface of the adsorbent. The dependence of Co (II) adsorption onto *Delonix regia* biomass is illustrated in Figure 1.

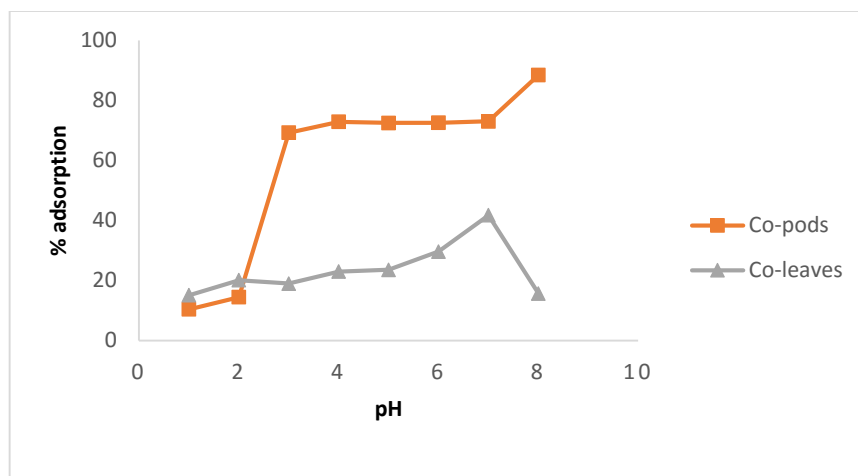


Figure 1: pH study of the sorption Co (II) ions on *Delonix regia* pods and leaves

Cobalt (II) is known to undergo hydrolysis in water and forms an insoluble aqueous complex with increase in solution pH (Kara *et al.*, 2003). This is borne in mind in studying the effect of solution's pH on the adsorption of cobalt (II). Figure 1 revealed a noticeable increase in the uptake of Co onto the pods from pH 2 to 4 after which it remained fairly constant until pH 7 while for Co adsorption onto the leaves a steady increase from pH 1 to pH 7 was observed. The fact that insoluble complexes were formed is not an indication of adsorption by the adsorbents but of its removal from the adsorbate solution by precipitation and as such this result was reported as % adsorption. Some authors such as Swelam *et al.*, 2016 and Kara *et al.*, 2002 pointed out in their works that percentage adsorption of cobalt (II) at high pH values included removal by precipitation. In consideration of these results further experiments were conducted using Co (II) solution at pH 4 while for the leaves maximum adsorption was considered at pH 6. Goyal and Agrawal (2005) reported that the uptake of Co (II) ions by activated carbons (granular and fibers) was maximum at pH 6 and decreased at higher pH values.

Contact Time study

An ideal sorbent is expected to rapidly adsorb metal ions in the first few minutes of interaction

with the solutions, to show if the *Delonix regia* biomass will be suitable for use as an adsorbent, it should satisfy this criterion and thus would be applicable in industrial based applications where process time and efficiency are very important (Vieira and Volesky, 2000). The result from this aspect of the study shown in Figure 2 revealed that *Delonix regia* biomass rapidly adsorb Co (II) ions in the first five to fifteen minutes of interaction with the adsorbate solutions. Amount of Co (II) removed increased with time up to 15 minutes (when 2.70 mg is adsorbed per gram of adsorbent) after which it remained fairly constant at 2.40 mg/g for adsorption on to *Delonix regia* pods. The adsorption of the metal ion onto the leaves powder was also rapid within the first fifteen minutes after which it steadily declined till the end of the time (300 minutes) used for the study. The fast uptake of the metal by *Delonix regia* will be a cost-effective advantage in industry as many batches of effluents could be treated within a short period of time. For ease of handling and experimental set up, a contact time of 30 minutes was used.

An optimum time of 15 minutes was reported for the sorption of Fe, Cu and Co ions using activated carbon prepared from *Recinius Communis Linn.* (Karthikeyan and Siva, 2008). Similarly, Moreno-Piraján and Giraldo, (2012) reported an optimum

time of 15 minutes for the adsorption of cobalt onto activated carbon obtained from orange peels

Kinetics modelling

Adsorption kinetics describes the rate of cobalt (II) ions uptake on *Delonix regia* and this rate in turn

controls the equilibrium time. The kinetics of adsorbate uptake is necessary for choosing optimum operating conditions for full scale batch process (Ghomri *et al.*, 2013).

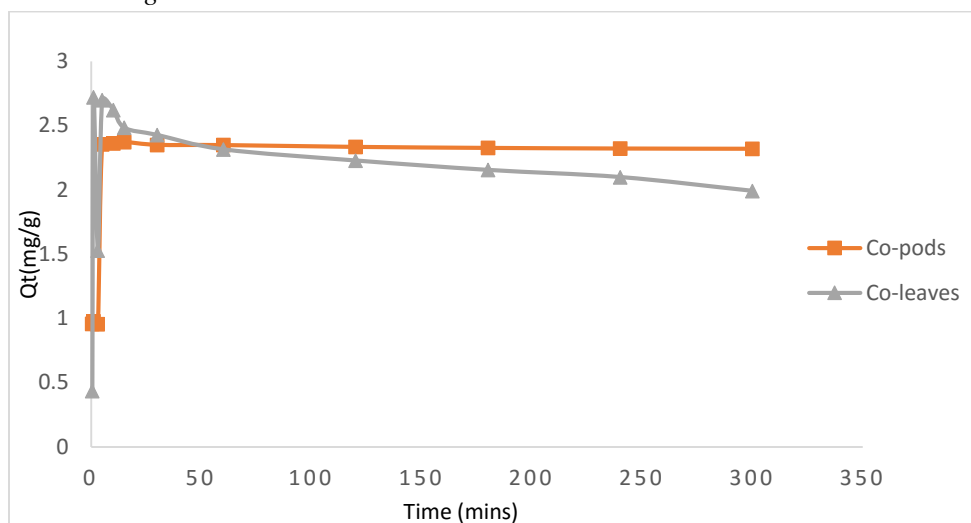


Figure 2: The effect of contact time on the adsorption Co (II) by *Delonix regia* pods and leaves

The kinetic parameters give information for designing and modelling processes and are useful insight for prediction of adsorption rate. The pseudo-first-order, pseudo-second-order kinetic and intra-particle diffusion models, were used to determine the mechanism of the sorption process. A linearized form of the pseudo-second order kinetic model expressed by Equation 3 was used to simulate the kinetic sorption process in order to obtain the specific rate constant of the process.

$$\frac{t}{Q_t} = \frac{1}{k_{2,ad}Q_{eq}^2} + \frac{1}{Q_{eq}t} \quad (3)$$

If second-order kinetics are applicable, the plot of t/Q_t against t should give a linear relationship, from which Q_{eq} and $k_{2,ad}$ can be determined from the slope and intercept of the plots (Ho and McKay, 1999), where $k_{2,ad}$ ($\text{g}\cdot\text{mg}^{-1}\cdot\text{min}^{-1}$) is the second order rate constant for the sorption, Q_{eq} and Q_t are the

amounts of adsorbent at equilibrium and at any time t , respectively (mg/g). The main assumption of pseudo second order kinetic model is that the rate limiting steps may be chemical sorption involving forces through exchange or sharing of electrons between the metal ions and the biomass (Al-Rub *et al.*, 2002).

Results obtained (Figure 3) showed that the process was well fitted to the pseudo-second-order kinetic model. Similar observations were reported by Babalola *et al.*, (2020) and Hansen *et al.*, (2010) whose experimental data obtained were well fitted to pseudo second order model. The correlation coefficients for all the adsorbents (*Delonix regia* pods and leaves powder, Peanut shells, Nut shells, Plum seeds, Eucalyptus bark, Olive pips, Peach stones, Pine sawdust) were higher than 0.9.

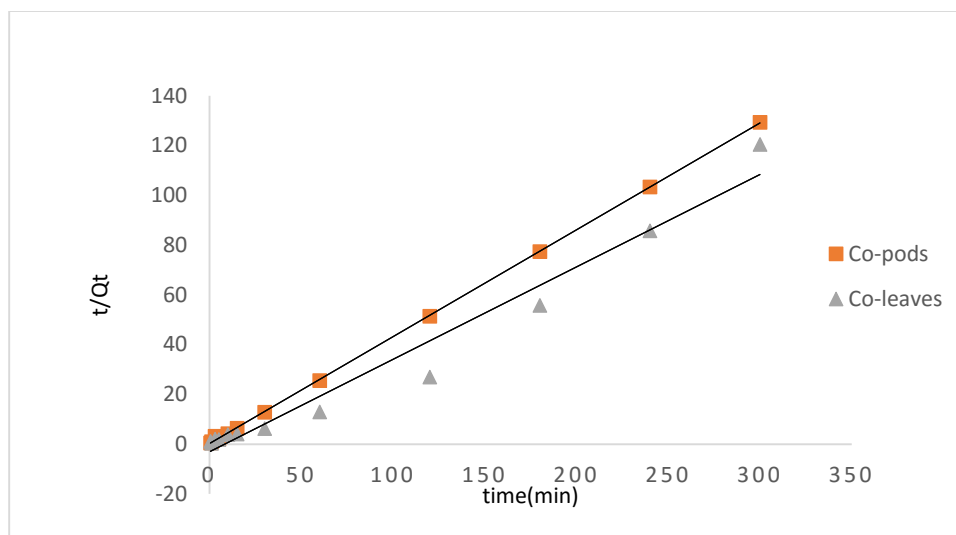


Figure 3: Pseudo-second order kinetics study of the adsorption of Co (II) by *Delonix regia* pods and leaves

The data obtained for the adsorption of Co (II) ions onto the pods had better correlation coefficient than

the leaves however the Q_e (Table 1) values suggest that the leaves have better sorption capacity

Table 1: Adsorption parameters obtained from the second order kinetic model for the sorption of Co (II) to *Delonix regia* pods and leaves

| Co (II) ions | k_2 (g.mg ⁻¹ min ⁻¹) | Q_e (mg/g) | R^2 |
|--------------|---|--------------|--------|
| Pods | -5.74 | 2.3 | 0.9997 |
| Leaves | -0.22 | 2.6 | 0.9694 |

Furthermore, the experimental data from contact time study was tested to show the contributions of intra-particle diffusion mechanism using the Weber and Moris equation shown in Equation 4 (Al-Rub *et al.*, 2004).

$$Q_t = k_{id}t^{1/2} + C \tag{4}$$

where k_{id} is a measure of diffusion coefficient (mg/min^{1/2}/g), Q_t is the amount of adsorbate adsorbed (mg/g) at any time t (min⁻¹) and C is the intra-particle diffusion rate constant (mg/g). The plot obtained (Figure 4) is not linear and did not pass through the origin an indication that intra-particle diffusion mechanism is not the only mechanism involved in the sorption of Co (II) ions unto *Delonix regia* biomass.

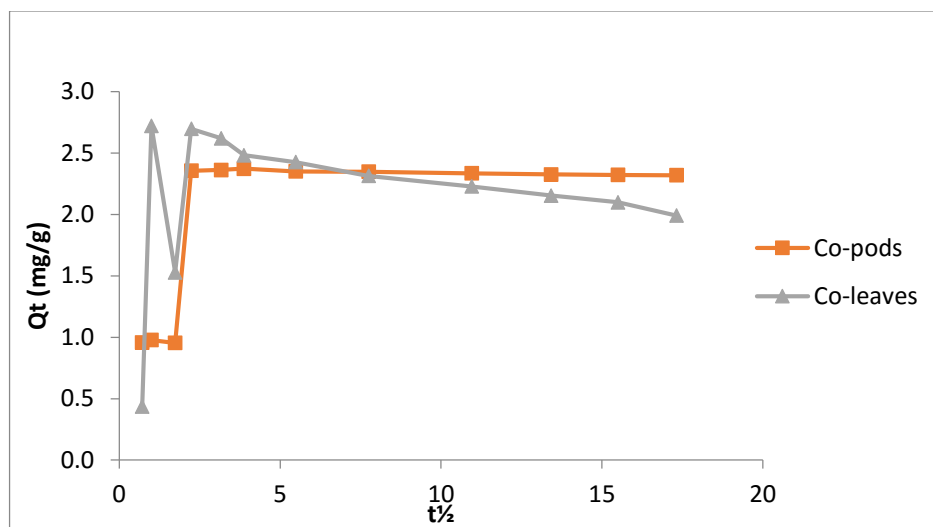


Figure 4: Intra-particle diffusion study of the adsorption of Co (II) by *Delonix regia* pods and leaves

Adsorption Equilibrium modelling

A study of the effect of changing the initial concentration of the metal ions while keeping the adsorbent dose and other factors constant during the adsorption experiment was carried out and the result is shown in Figure 5.

The result revealed that there was an increase in the uptake of cobalt (II) ions by *Delonix regia* as the concentration of the metal ions in solution was increased. The increase in cobalt uptake onto the pods was linear to an initial concentration of 100

ppm and thereafter decreased slightly. For the leaves, it was an increasing uptake irrespective of the initial concentration used.

The increase in uptake with increasing concentration was due to more metal ions occupying the fixed number of active sites on the biomass surface. It thus implied that *Delonix regia* could be used to effectively remove this targeted metal from wastewater if the concentration in the wastewater is within the linear experimental concentration range.

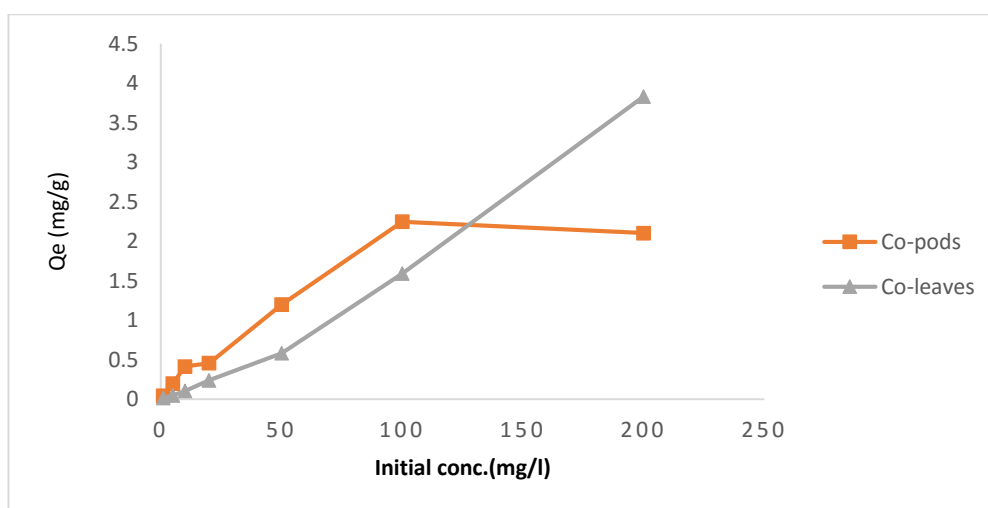


Figure 5: Effect of initial Co (II) ion concentration on adsorption by *Delonix regia* pods and leaves.

One of the basic requirements necessary for the design of adsorption systems is the equilibrium data and adsorption isotherm models are mathematical representation of the adsorption equilibrium of metal ions on to the adsorbent.

An adsorption isotherm model gives information on the amount of adsorbent needed to remove a unit mass of pollutant under the system conditions (Aksu and İsoğlu, 2005). It can be derived from many theoretical models with Langmuir and Freundlich models as those commonly used for describing adsorption isotherms at a constant temperature for water and wastewater treatment applications (Carbonell, 1986, Langmuir, 1918).

The Langmuir and Freundlich isotherms were used to model the equilibrium data obtained from the adsorption of Co (II) ions onto *Delonix regia* pods and leaves, to determine the isotherm parameters.

From the Langmuir isotherm shown in Equation 5, it is possible to calculate the Langmuir monolayer adsorption capacity (Q^0 in mg/g) and the Langmuir constant (b) which is the constant related to the energy of adsorption. Using the slope and intercept of the plot of C_e/Q_e against C_e shown in Figure 6, the values of the Langmuir constant presented in Table 2 were calculated.

$$\frac{C_e}{Q_e} = \frac{1}{Q^0 b} + \frac{C_e}{Q^0} \quad (5)$$

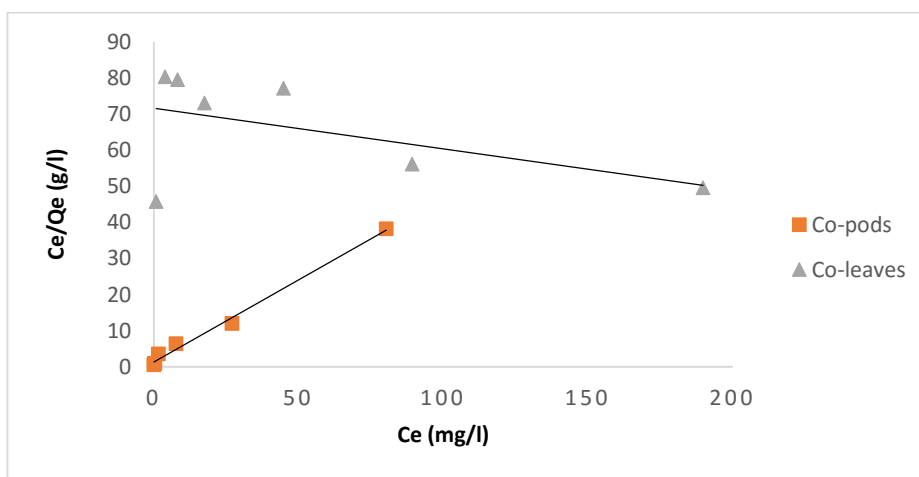


Figure 6: Plot of Langmuir Isotherm for the adsorption of Co (II) by *Delonix regia* pods and leaves

The r^2 values obtained from the Langmuir plot (Figure 6) did not show good correlation implying that the Langmuir Isotherm model is suitable for the adsorption process of cobalt (II) ions onto *Delonix regia* pods but not unto the leaves.

Furthermore, a dimensionless equilibrium parameter K_R shown in Equation 6 can be used to express the important features of the Langmuir constant (Arami *et al.*, 2005).

$$K_R = \frac{1}{1 + bC_i} \quad (6)$$

The value of the parameter K_R indicates whether the adsorption is favourable by Langmuir model or not. When $K_R = 0$ indicate an irreversible isotherm; $0 < K_R < 1$ indicate a favourable isotherm; $K_R = 1$ it is a linear isotherm and $K_R > 1$ the isotherm is termed unfavourable.

The K_R values obtained for the sorption process onto the pods were between 0.030 and 0.377 while that of the leaves ranged between 0.039 and 0.889, these values showed that there is a favourable sorption of cobalt (II) ions unto *Delonix regia* pods.

Table 2: Adsorption parameters of the Isotherm Models for the sorption of Co (II) to *Delonix regia* pods and leaves

| Co (II) | Langmuir Isotherm | | | Freundlich Isotherm | | |
|---------|-----------------------|---------|----------------|---|-------|----------------|
| | Q ⁰ (mg/g) | b(l/mg) | r ² | K _f (mg/g(L/mg) ^{1/n}) | n | r ² |
| Pods | 2.1997 | 1.6537 | 0.9923 | 0.3953 | 2.111 | 0.9424 |
| Leaves | 8.8968 | 0.1243 | 0.2686 | 0.0154 | 0.996 | 0.9846 |

The Freundlich isotherm is an empirical equation used to describe adsorption on heterogeneous surfaces is expressed its linear form in Equation 7 (Özcan and Özcan, 2004).

$$\text{Log } Q_e = \text{Log } K_f + \frac{1}{n} \text{Log } C_e \quad (7)$$

K_f and n are Freundlich constants, K_f (mg/g (L/mg)^{1/n}) being the adsorption capacity of the sorbent and n giving an indication

of the favourability of the adsorption process. An indication of the favourability of adsorption is depicted by the value of n . Values of $n > 1$ represent favourable adsorption condition (Ho and McKay, 1998). A plotted graph of Log (Q_e) against Log (C_e) (Figure 7) was employed to calculate the values of K_f and n . Values obtained, presented in Table 2, showed the Freundlich isotherm fitted well for describing the adsorption of cobalt (II) ions unto *Delonix regia* pods and leaves.

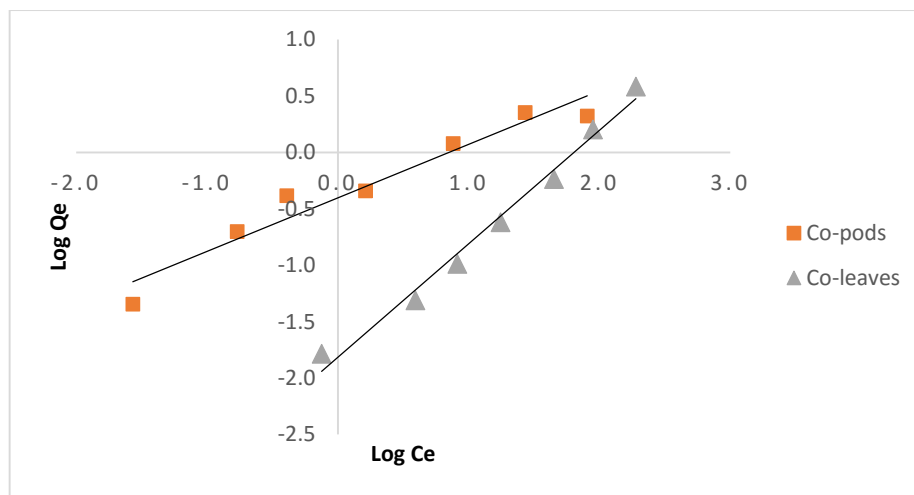


Figure 7: Plot of the Freundlich Isotherm for the sorption of Co (II) on *Delonix regia* pods and leaves

The Effect of adsorbent dose

The effect of adsorbent dosage on the adsorption of Cobalt (II) ions by *Delonix regia* is shown in Figure 8. As evident in the Figure, increasing the amount of *Delonix regia* biomass (pods and leaves) resulted in an increase in the percentage of cobalt

(II) adsorbed. The increase noticed is significantly attributed to an increase in the available binding sites on the adsorbent as dosage is increased because when the initial concentration of metal is fixed, increase in adsorbent dosage provides greater surface area and availability of more active sites, thus leading to the enhancement of metal ion

uptake (Kumar and Gaur, 2011). The study also showed that the pods of *Delonix regia* had better adsorption with increase in dosage, as adsorption

percentage as high as 80% was recorded when the pod was considered whereas the highest adsorption with the leaf is 25%.

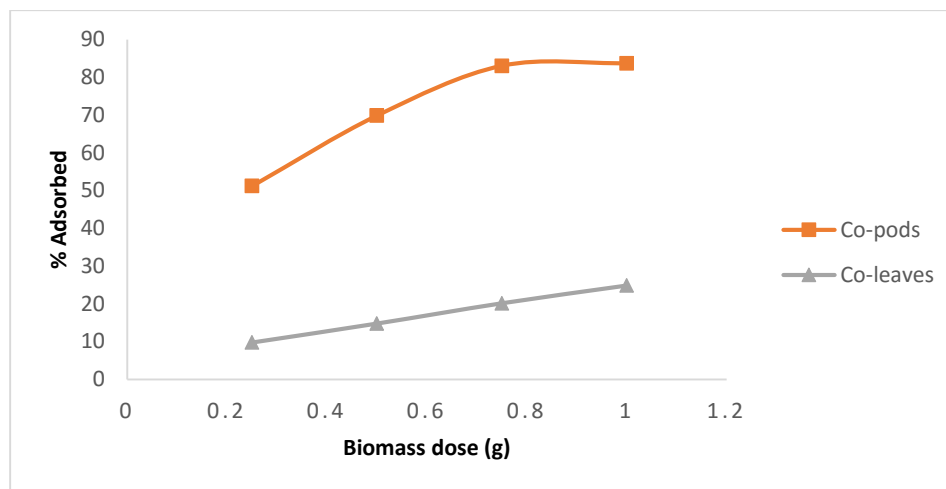


Figure 8: The effect of Adsorbent dose on the adsorption of Co (II) by *Delonix regia* pods and leaves

The effect of ionic strength

The effects of the adsorbate solution's ionic strength on the adsorption of Co (II) ions by *Delonix regia* pods and leaves were considered. The effect of the total electrolyte composition in a solution is a major characteristic of solutions with dissolved ions; this property referred to as solution's ionic strength affects the activity of aqueous solutions. The result presented in Figure 9 showed the effect of different concentration of sodium nitrate on the adsorption process revealed that the presence of NaNO_3 has no significant effect on the percentage of Co (II) ions adsorbed by the biomass at low ionic concentration but as ionic concentration is increased, there is a marked reduction in the adsorbed percentage.

Within the concentration of ionic solution (0.001-1.00 M NaNO_3) tested in this work, we discovered that percentage adsorption of Co (II) ions on to the pods was decreased from 85% to 84% with concentration change from 0.001 to 0.01 M and further decreased from 79% to 74% when concentration increased from 0.05 to 0.1 M while the percentage adsorption unto the leaves showed a decrease from 60% to 54%. An increase in solution's ionic strength results in a decrease in activity of the solution and this will consequently result in a decrease uptake of metal by the adsorbent (that is, reduced capacity). This could explain the decrease observed in the uptake of Co (II) ions by *Delonix regia* when the ionic strength of the aqueous solutions were increased by dissolving different concentration of sodium ion.

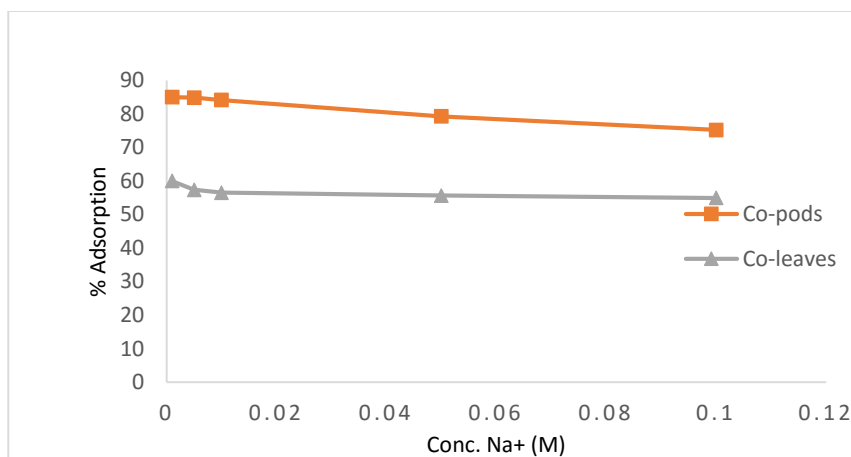


Figure 9: The effect of ionic strength on the adsorption of Co (II) by *Delonix regia* pods and leaves

Desorption Study

The result of the experiment presented in Figure 10 is the desorption experiment which was done to determine the potency of the biomass for possible re-use.

From the result, higher concentration of the acid desorbed more Co (II) from the pods but from the leaves, the various concentration of nitric acid (from 0.1 to 1.0 M) had little effect on desorbing

the adsorbed Co (II) ions. Nitric acid (0.1 - 1.0 M HNO₃) was able to desorb between 58.75% up to 61.41% of adsorbed Co (II) ions from the pods. Kordialik-Bogacka, (2011) and Li *et al.*, (2009) reported that high concentration of desorbing agents (acid) could destroy the adsorbent. For the leaves, less than 35% of Co (II) ions could be desorbed from the leaves irrespective of nitric acid concentration used, thus the possibility of reusing the leaves powder may not be feasible.

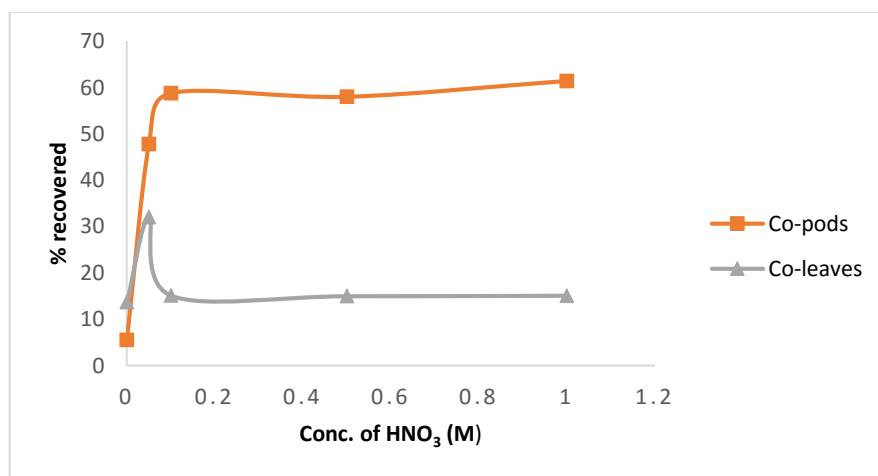


Figure 10: Desorption Study of Co (II) adsorbed on *Delonix regia* pods and leaves

CONCLUSION

The leaves and pods of an agro-waste material, *Delonix regia* was used for the removal of Co (II)

ions from synthetic wastewater. The results of this study indicated that *Delonix regia* can be successfully used to remove Co (II) ions from aqueous solutions especially at low concentrations.

The adsorption of Co (II) ions largely depended on pH of the adsorbate solution, contact time of interaction between the adsorbate and adsorbent, initial concentration of adsorbate solution and ionic strength. The optimum pH for the adsorption of Co (II) ions by *Delonix regia* pods was pH 4 while pH 6 was the optimum for the leaves. The pods of *Delonix regia* show more promising ability in the adsorption of Co (II) ions as adsorption percentage of 67.5% (2.25 mg/g) and 24.5% (1.59mg/g) were recorded for the pods and leaves respectively at the 100 ppm working concentration in this experiment. The adsorption of cobalt (II) ions unto the pod was adequately modelled by both Langmuir and Freundlich isotherms while its adsorption unto the leaves was modelled by the Freundlich isotherm and the sorption kinetics of cobalt (II) ions onto both materials followed the pseudo-second-order kinetic model. The presence of sodium ions had no effect on adsorption at low concentration but at higher concentration, percentage of cobalt adsorbed reduced. This work has shown that, *Delonix regia* pods could be used as a low-cost sorbent for the removal of cobalt (II) ions from aqueous solutions.

CONFLICT OF INTEREST

We declare that there is no conflict of interest.

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