Adsorption of Zinc from Water by Coconut Coir Carbon

by

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CERTIFICATION OF APPROVAL

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Civil Engineering Programme
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Approved by,

(Prof. Malay Chadhuri)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

FAERAH BT NASIR

ABSTRACT

The research is to investigate the adsorption of zinc in wastewater by coconut coir carbon. Industrial wastewater is increasingly contaminated by toxic metal ions which cause serious environmental problem. There is a need to remove zinc from water/wastewater to meet the standard for discharge of 5 milligrams per liter (mg/l) Department of Environment (2005). The objective of the study is to produce low cost adsorbents from readily available material to remove zinc from water/wastewater. The adsorbent is coconut coir carbon which is prepared through chemical activation process by treating the coir with potassium hydroxide and subjected to physical activation at 700-750 °C for 30 minutes in an oxygen-free oven. The optimum conditions for removal of zinc by studying the effect of contact time, pH, and initial concentration of zinc, and adsorbent particle size on the zinc adsorption. The experiment conducted shows that the optimum contact time for batch studies was 3 hours and optimum pH was 6. Both optimum conditions were used to evaluate the effect of adsorbent dose which shows the maximum adsorption at adsorbent concentration of 1 g/L. The adsorption was found to follow Langmuir isotherm with Langmuir maximum capacity X_m of 6.184. The adsorption follows pseudo-second order kinetics with initial rate of 1.75 mg g^{-1} min^{-1}. Adsorption of zinc from water by coconut coir carbon was proved to be effective as removal method, since coconut coir is cheap and readily available, it has the potential to be used for removal of zinc from water.

ACKNOWLEDGEMENT

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CHAPTER 1

INTRODUCTION

1.1 Background of the Study

In developing countries, many small industries generate considerable amount of heavy metals in wastewater which are discharged directly to the environment without any wastewater treatment. Discharging metal ions to environment can pose health hazard if the limit is exceeded. Continuous discharge of metal ions to the watercourses even though the limit is not exceeded, can potentially pose long-term contamination as heavy metals are concentrated by bioaccumulation (Al-Duri *et al.*, 1998).

Due to the increasing awareness of heavy metals accumulation, legislation to control water pollution in Malaysia is introduced. However, conventional methods of removal such as ion exchange, chemical precipitation, ultrafiltration, and cementation are not economically feasible for small industries.

Adsorption by using activated carbon is an alternative method of metal ion removal. However, it is not economical to use commercially activated carbon in developing countries. Thus, alternative material to prepare activated carbon which is cheaper and readily available need to be studied.

1.4 Scope of the Study

Batch studies will be conducted to assess zinc adsorption efficiency of coconut coir carbon which will include the study of the effect of pH, contact time and adsorbent concentration to the adsorption of zinc.

This study will be using synthetic zinc solution as adsorbate and potassium hydroxide is used in the coconut coir carbon activation process. The expected completion of the study is one year. Literature reviews will be conducted in first half of the year as well as the preparation of coir and coir carbon and batch studies be conducted in second half of the year.

CHAPTER 2
LITERATURE REVIEW

2.1 Zinc in Wastewater

Zinc in wastewater is contributed from various industries such as paints, coatings, metal molding and casting industries. In small-scale industries, considerable amount of zinc is discharged directly to the environment without any wastewater treatment. Continuous discharge of zinc to watercourses, even though the limit is not exceeded, can potentially pose long-term contamination as heavy metals are concentrated by bioaccumulation. (Al-Duri et al., 1998).

2.2 Legislations and Guidelines

Wastewater from industries must be pre-treated before being discharged. Discharge limit of zinc concentration from industrial wastewater is 1 mg/l accordance to both Standard A and Standard B (Appendix E).

2.3 Methods of Zinc Removal

There are several methods of removal of zinc from wastewater, such as ion exchange, chemical precipitation, ultrafiltration, and cementation. To remove zinc from wastewater using these methods are costly even for large-scale industries. Alternatively, large-scale industries use methods, such as adsorption on activated carbon. Even though commercial activated carbon costs less compared to other conventional methods, it is seemingly not feasible for small-scale industries. Thus, a wide range of research was done to find feasible alternatives for commercial activated carbon. According to Kaya and Oren (2005), zinc in aqueous solution can be adsorbed by bentonite. The behavior of adsorption is strongly dependent on the pH of the solution. The adsorption efficiency increases at high pH values (above pH value of 8).

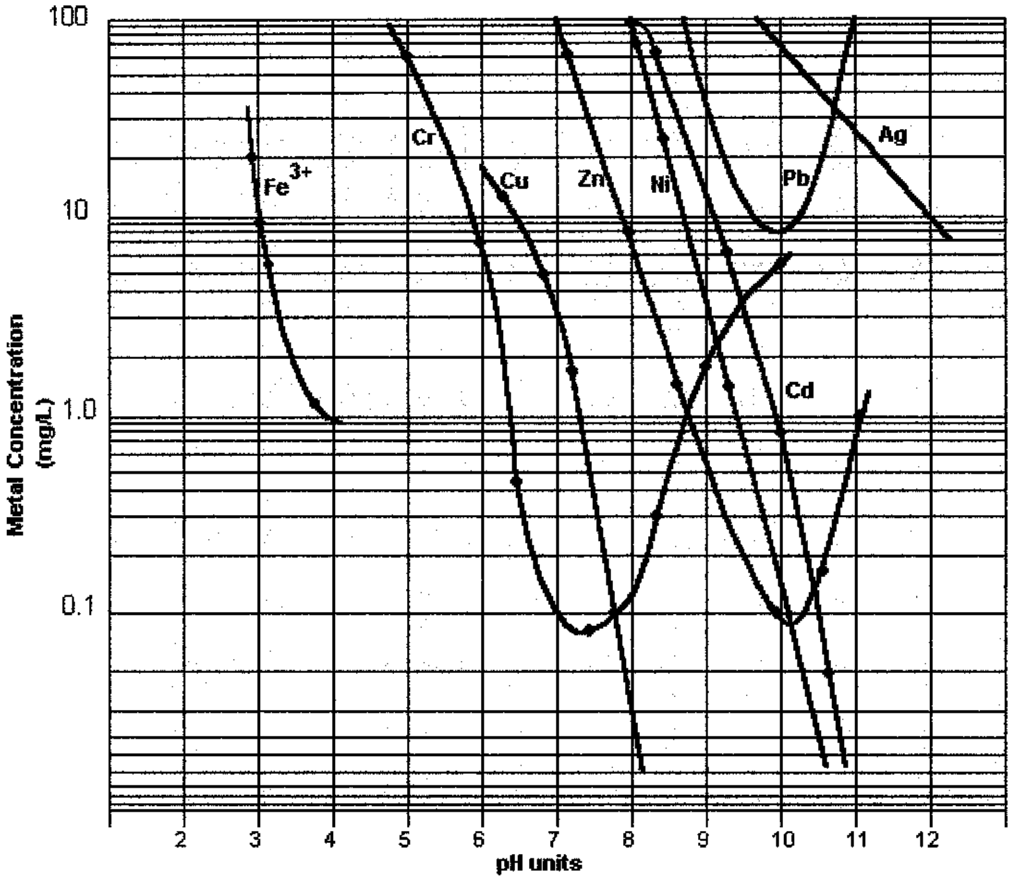

Figure 2. 1: Solubility curve for Metal Ions (Metcalf and Eddy, Inc (2004))

Figure 2.2 shows the solubility for metal ion including zinc. It shows that the solubility for zinc depends on pH of solution and metal concentration. In order to investigate the zinc adsorption, overlapping between adsorption and precipitation must be ruled out. pH of solution and zinc concentration must be adjusted to ensure precipitation does not contribute to zinc removal.

2.3.1 Carbon Adsorption

Activated carbon is useful in water treatment as it can remove organics from water by adsorption. It acts as an effective adsorbent material due to its large number of micropores which provide a large surface area relative to the size of the actual carbon particle and its visible exterior surface. There are three steps in preparation of activated carbon which are dehydration, carbonization, and activation. Activated carbon is used in water treatment in several forms, typically powdered and granular to remove variety of impurities in water. (Kvech and Tull, 1997)

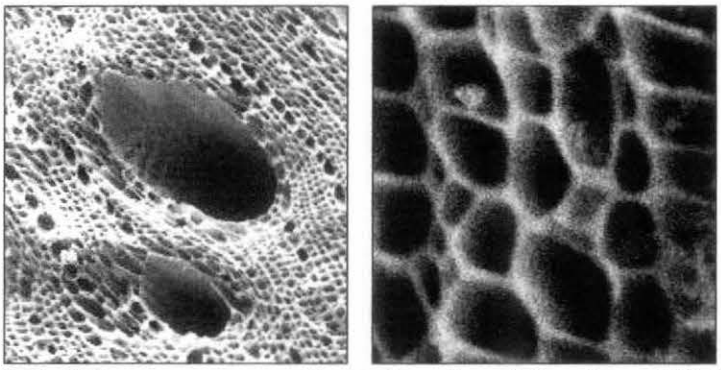

Figure 2. 2: Micropores on activated carbon (Kvech and Tull, 1997)

2.4 Adsorption

Adsorption of substances to activated carbon is through 3 basic steps: after contact between substances and activated carbon, the substances adsorb to the exterior of the carbon granules; then the substances move into the carbon pores before being adsorbed to the interior walls of the carbon. The adsorption efficiency of activated carbon decreases over time. After the adsorption capacity is reached, the activated carbon will need to be replaced or regenerated. To predict the adsorption capacity of the activated carbon, isotherms which are empirical relations are used. There are three well known isotherms: Freundlich, Langmuir and Linear. (Kvech and Tull, 1997)

2.4.1 Adsorption Isotherms

2.4.1.1 Freundlich Adsorption Isotherms

Isotherms were used for fitting the experimental data in adsorption studies to understand the extent and degree of favorability of adsorption (Treybal, 1981). Freundlich linearized equation is given by

$$LogX / M = LogK + \frac{1}{nLogCe} \tag{1}$$

Where X is the amount of adsorbate adsorbed, M is the weight of carbon, X/M is the concentration in the adsorbed phase, C_e is the equilibrium concentration of adsorbate in solution after adsorption, K and $1/n$ are constants indicating adsorption capacity and intensity of adsorption: respectively.

The Freundlich constant, n should have values lying in the range of 1 to 10 for classification as favorable adsorption (Rao and Bhole, 2001; Raji et al., 1997).

2.4.1.2 Langmuir Adsorption Isotherms

Langmuir Adsorption Isotherm is given by

$$\frac{C_e}{q_e} = \frac{1}{X_m k} + \frac{C_e}{X_m} \tag{2}$$

Where Ce is the equilibrium concentration of adsrobate in solution after adsorption, q_e is the concentration in the adsorbed phase and X_m is the Langmuir maximum capacity.

The Langmuir adsorption isotherm was developed by assuming a fixed number of accessible sites are available on the adsorbent surface, all of which have the same energy and adsorption is reversible. Equilibrium is reached when the rate of adsorption of molecules onto the surface is the same as the rate of desorption of molecules from the surface (Metcalf and Eddy (2004)).

2.4.2 Kinetics of Adsorption

Kinetic models were used in quantifying the changes in sorption with time. There are two well known kinetic models which are first-order Lagergren equation and pseudo-second order equation.

2.4.2.1 First order kinetic model

Lagergren equation is given by

$$Log(Qe - Q) = LogQe + \left(\frac{K_{ad}}{2.303}\right)t \tag{3}$$

Where Q and Qe are the amounts of metal ion adsorbed (mg/g) on the carbon at time t (min) and at the equilibrium time respectively, and K_{ad} is the rate constant of adsorption (min^{-1}).

2.4.2.2 Pseudo-Second order kinetic model

Pseudo second order equation is given by

$$\frac{t}{Qt}=\frac{1}{2kQ_e2}+\frac{t}{Qe} \qquad (4)$$

Where Q_t is the amounts of metal ion adsorbed (mg/g) on the carbon at time t (min), Q_e is the amount of metal ion adsorbed at equilibrium and k is constant.

Pseudo second order equation gives the initial rate of adsorption, h which is given by

$$h=2kQe^2 \qquad (5)$$

2.5 Raw Carbon Source

To prepare activated carbon, raw carbon source must be selected. There are certain criteria in choosing carbon source such as pore structure and particle size. Another important criterion is the availability and cost of the carbon source. Activated carbon preparation most often includes chemical and thermal activation. Chemical activation is done by exposing carbon to additional chemical or other oxidizing agents, while thermal activation is achieved by subjecting the carbon source to high temperature usually 500-700°C in oxygen-free condition. The resulting activated carbon can be classified according to density, hardness, and other characteristics. (Kvech and Tull, 1997)

2.6 Waste Material Adsorption Capacity

A number of researches were done to evaluate the capacity of waste material, such as microbial mass, peat, compost, leaf mould, palm press fibre, coal, straw, wool fibre and rice milling to adsorb metal from water (Forster and Wase, 1997). Another study examined coir as a biosorbent of copper and lead (Al-Duri et al., 1998). A study of removal of heavy metals from wastewater by adsorption on coir pith activated carbon was also conducted (Santhy and Selvapathy, 2004). A study to evaluate the adsorption of zinc from aqueous solution to bentonite was reported (Kaya and Oren, 2005) and adsorption of cadmium (II) and zinc (II) metal ions from binary aqueous solution by rice husk ash (Srivastava et al., 2007).

2.7 Chemical Modification

Numerous chemicals have been used to modify experimental material in evaluating heavy metal adsorption. This includes mineral and organic acids, bases, oxidizing agent and organic compounds. Some of the treated adsorbents show good adsorption capacities for Cadmium, Copper, Lead, Zinc and Nickel (Wan Ngah and Hanafiah, 2007). A study of coconut coir pith as a biosorbent for the removal of chromium (VI) was done after modification with a cationic surfactant, hexadecyltrimethylammonium bromide (Namasivayam and Sureshkumar, 2007). According to Gupta and Ali (1999), bagasse fly ash was treated with hydrogen peroxide as an oxidizing agent before use to remove copper and zinc from wastewater. Potassium hydroxide was used as the oxidizing agent in the study of coconut coir pith activated carbon adsorption efficiency in removing heavy metals from wastewater (Santhy and Selvapathy, 2004).

2.8 Abundance of Coconut Coir in Malaysia

In Malaysia, at least 120 million coconuts are produced annually. Thus, as a by-product of coconut production, coconut coir is available in large amount at a minimal cost. Coconut coir consists of functional groups such as carbonyl, carboxyl and hydroxyl which are thought to have the potential to bind metal ions (Al-Duri et al., 1998). Raw coir pith has been used as an adsorbent for the removal of dyes (Namasivayam et al., 2001) and chromium (VI) (Sumathi et al., 2005) from aqueous solution.

CHAPTER 3

METHODOLOGY

3.1 Flow chart

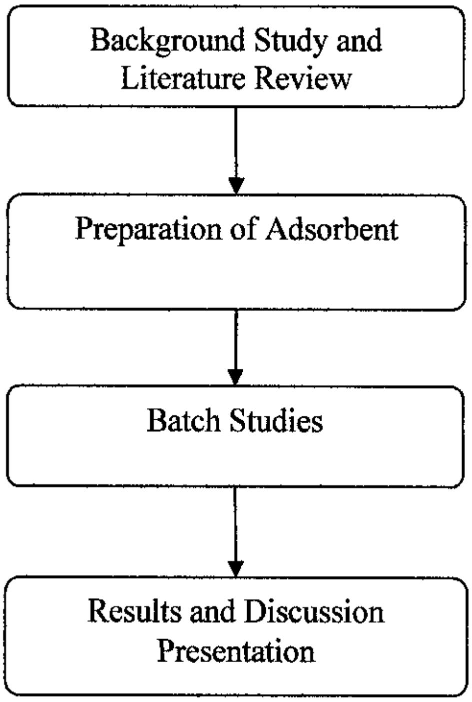

Figure 3. 1: Study Methodology

3.2 Preparation of Adsorbent

Coconut coir was obtained from waste generated within Universiti Teknologi Petronas surrounding which was a by-product of the local coconut drink industry.

The raw material was blended to smaller particle before washed several times with distilled water to remove contaminants and dried at 105°C for 24 hours.

The dried coconut coir was treated with 10% potassium hydroxide which was prepared by adding 100 ml distilled water to 10 g of potassium hydroxide. The potassium hydroxide treated coconut coir was subjected to activation at 800°C for 30 minutes using a nitrogen atmosphere furnace.

The resulted carbon was washed repeatedly using distilled water and then with 10% hydrochloric acid. The carbon was washed again with distilled water to remove free acid before dried at 105°C for 24 hours. The coconut coir carbon was ground to finer size by using mortar and pestle and sieved to 600μm particle size before use in studies.

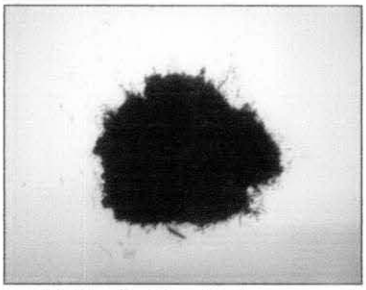

Figure 3. 2: Activated coconut coir

3.3 Batch Studies

Batch studies were conducted using shaker bottle. Zinc solution was put into shaker bottle and an adsorbent was put into contact with zinc solution. The shaker bottle was rotated on a rotary mechanical shaker.

3.3.1 Test for Contact Time

To determine the optimum contact time, an experiment was conducted by preparing 5 samples of 100 ml 10 mg/l solution. 1g/l coconut coir carbon was used throughout the experiment. The samples were rotated on a rotary mechanical at 150 rpm at 25°C. The samples were taken out every hour and filtered through Whatman No.1 filter paper before being tested using spectrophotometer.

3.3.2 Test for Effect of pH

After optimum contact time was obtained, the effect of solution pH is assessed. The pH of zinc solution was adjusted using 0.1 M NaoH or 0.1 M HCl. 1 g/l coconut coir carbon is used throughout the experiment. The samples were rotated using a rotary mechanical shaker at 150 rpm at 25°C for optimum contact time. The samples were filtered through Whatman No.1 filter paper before being tested using spectrophotometer. All pH values were measured using pH meter.

3.3.3 Test for Effect of Adsorbent Dose

The effect of adsorbent dose was assessed by preparing seven samples of zinc solution of 10 mg/l with optimum pH. Adsorbent dose was varied to 0.2, 0.4, 0.6, 0.8, 1.0, 1.2 and 1.4 g/l. The solutions were rotated on an orbital shaker for optimum contact time. The reaction mixtures were filtered through Whatman No.1 filter paper. The concentration of zinc in the filtrate was measured using spectrophotometer.

3.4 Adsorption Analysis

Initial and final concentration of zinc solutions were tested using DR 2800 spectrophotometer. The reagent used was zinc HACH pillows and Cyclohexanone. All pH values were measured using pH meter.

3.5 Hazard Identification

Table 3.1 shows the list of possible hazard faced during the study completion.

Table 3. 1 : Material hazard identification (Chemical Safety Data, http://ptcl.chem.ox.ac.uk/)

No	Material	Hazard
1	Zinc (powder)	Contact with the eyes can cause irritation Powdered zinc is highly flammable
2	Hydrochloric acid (HCl)	Highly corrosive to skin and mucous membranes Repeated exposure causes erosion of teeth Strong chlorine odor detectable at 1-5 PPM.
3	Potassium Hydroxide (KOH)	Contact with the eyes can cause serious long-term damage Potassium hydroxide solutions are corrosive A significant amount of heat is released when potassium hydroxide dissolves in water
4	Sodium Hydroxide (NaOH)	Contact with the eyes can cause serious long-term damage Sodium Hydroxide solutions are corrosive Significant heat is released when sodium hydroxide dissolves in water
5	Cyclohexanone	Inhalation may cause cough, sore throat, or drowsiness Flammable

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

This chapter details the results which were obtained during the study. The effect of three parameters which are contact time, pH and adsorbent dose were presented in figures and discussed consequently. Adsorption isotherms and kinetics of adsorption are also analyzed and discussed to evaluate the adsorption behavior.

4.2 Effect of contact time

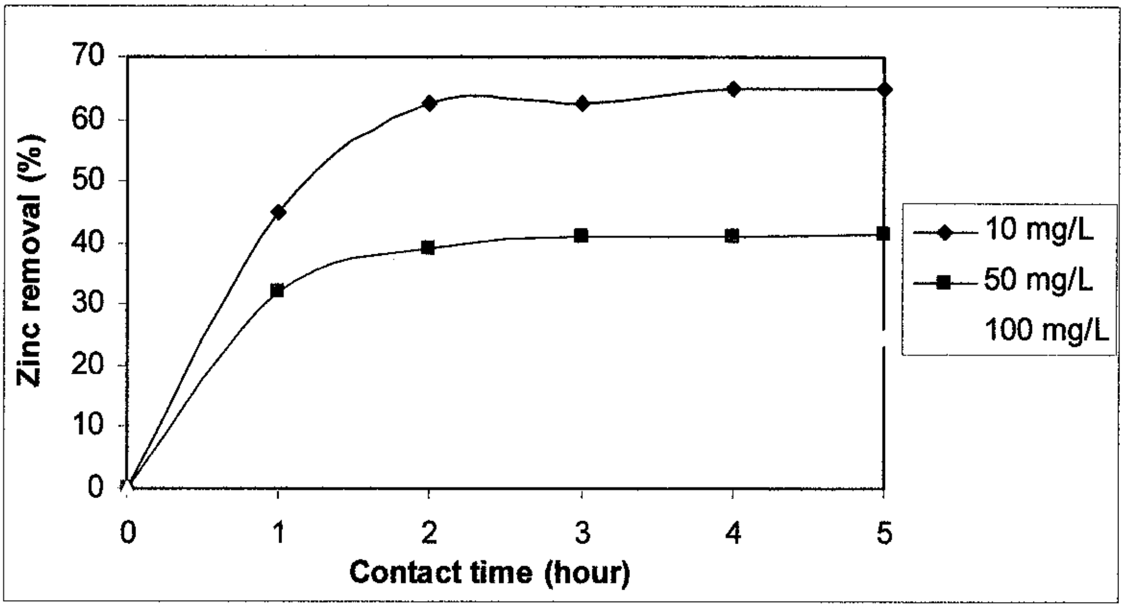

Figure 4. 1: Effect of contact time on adsorption of zinc by coconut coir carbon; 1 g/l adsorbent; initial pH 3.6

The removal of zinc at five different contact hours is shown in Figure 4.1. The maximum adsorption is 65%, for 10 mg/l initial concentration of zinc, 41% for 50 mg/l zinc initial concentration, and 25% for 100 mg/l of zinc initial concentration where all readings are taken at time two hours.

The rate of uptake is fast in the first hour, less at the second hour and constant after two hours where there was no significant decrease in zinc concentration. This is because the equilibrium was attained in which rate of adsorption of molecules onto the surface is the same as the rate of desorption of molecules from the surface. The decreasing adsorption rate is due to the occurrence of rapid external mass transfer followed by a slower internal diffusion process (Wong et al, 2003).

The maximum value of zinc removal at higher initial concentration is less of compared to lower initial concentration. This is because higher concentration of zinc have higher surface loading if compared to lower zinc concentration. More number of zinc ions will be competing for same adsorption sites thus resulting in lower percentage of zinc removal.

4.3 Effect of pH

Figure 4.2 represents the effect of pH on the adsorption of zinc on coconut coir carbon. As shown in figure below, the adsorption of zinc depends on the pH of the solution. The result shows that the adsorption of zinc is optimum between pH 4 and pH 7 in which the removal of zinc achieved 94.05% at pH 6.

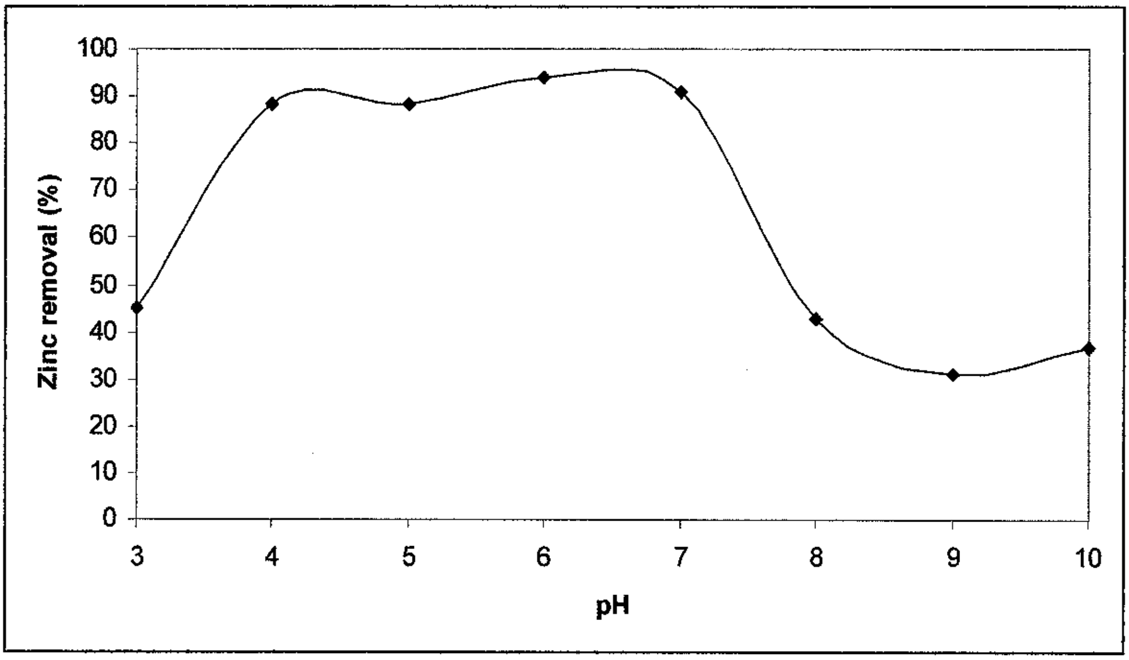

Figure 4. 2: Effect of pH on adsorption of zinc by coconut coir carbon; 10 mg/l zinc; 1 g/l adsorbent

At pH 3, the removal of zinc is lower if compared to less than pH 4 to pH 7 as the surface of the adsorbent is surrounded by hydronium ions (H^+), which prevented zinc from approaching the binding sites on the adsorbent (Wong et. al., 2003).

Consequently, the decrease of adsorption capacity above pH 8 was due to the formation of $Zn(OH)_2$. The hydroxide precipitation occurred at high pH and thus reduces the amount of free metal ions which can be bind (Hasan et al.,2000). Zinc removal by coconut coir carbon overlaps with zinc precipitation in the alkaline region (above pH 7). It is not certain that adsorption is the only removal mechanism, thus less than neutral pH should be considered as optimum pH for the removal. In this study, the result shows that the highest zinc removal achieved at pH 6.

The effect of adsorbent dose to zinc removal was conducted after adjusting the zinc solution pH from initial pH of 3.6 to pH6.

4.4 Effect of adsorbent dose

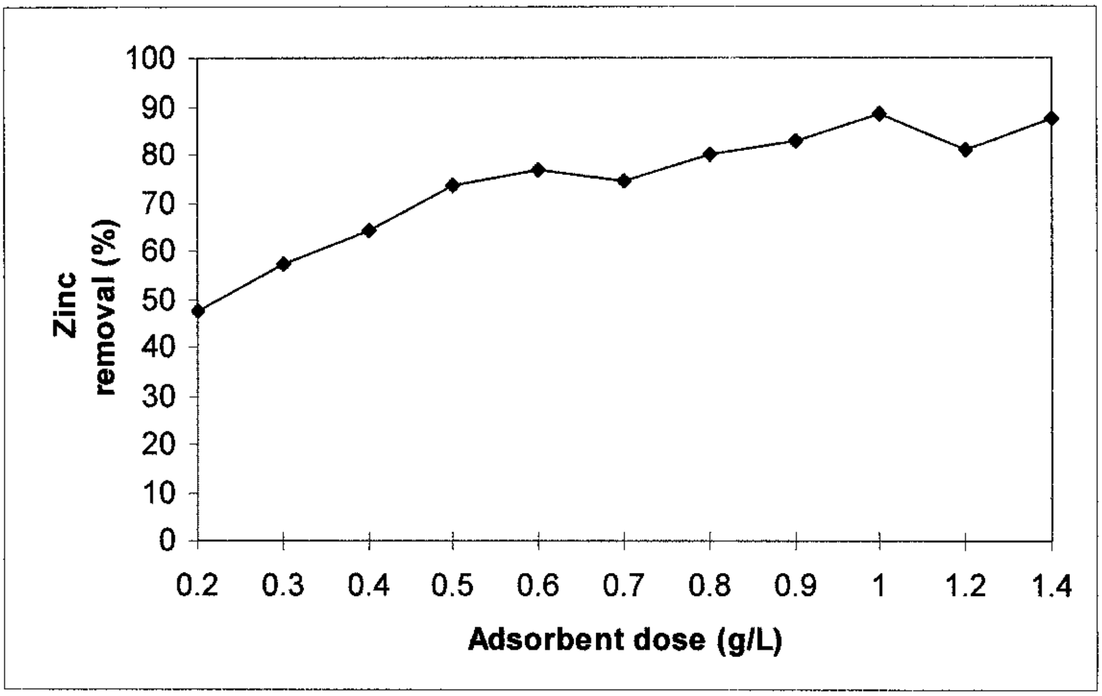

Figure 4. 3: Effect of carbon dose on adsorption of zinc by coconut coir carbon; 10 mg/l zinc; pH 6

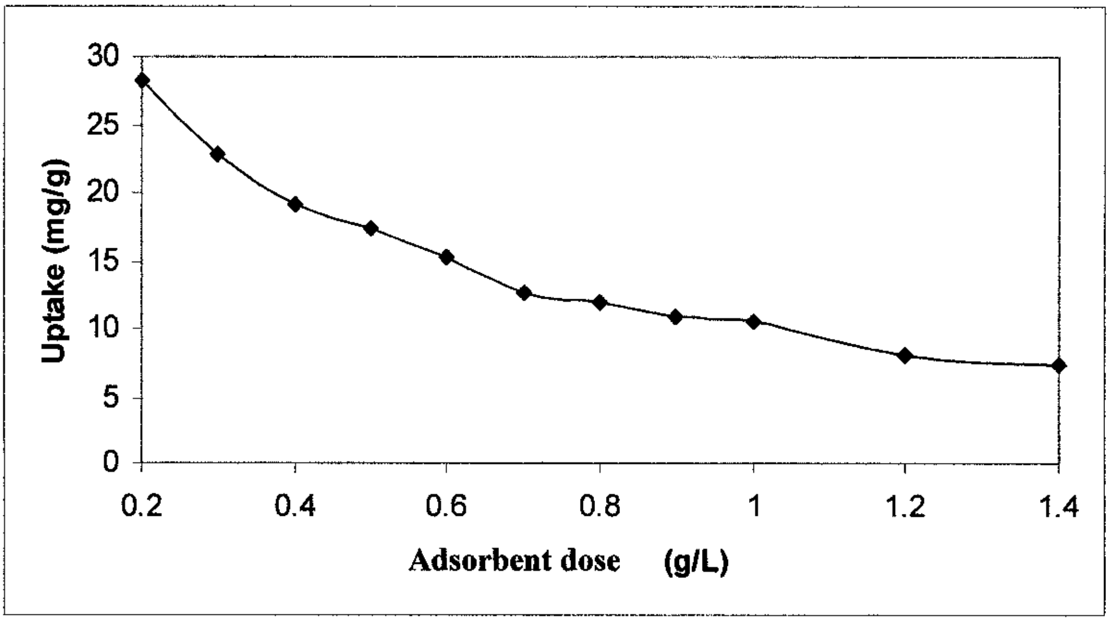

Figure 4.4: Effect of carbon dose to zinc uptake; 10 mg/l zinc; pH 6

Figure 4.3 shows the effect of adsorbent dose to the adsorption of zinc by coconut coir carbon. The removal of zinc ion increased with increase in carbon dose. The increase in removal of zinc ion is due to the availability of more surface functional groups as carbon doses increases.

4.5 Adsorption Isotherm

4.5.1 Freundlich Isotherm

The uptake of zinc by coconut coir carbon was evaluated using the linearized form of Freundlich isotherm equation (1).

$$LogX/M = LogK + \frac{1}{nLogCe} \tag{1}$$

The data was taken from the results if varying adsorbent dose from 0.2 g/l to 1.4 g/l (Figure 4.3). This plot is for initial concentration of 10 mg/l and contact time of three hours. As shown in figure below, the straight line nature of the plot indicates that the adsorption follows Freundlich type.

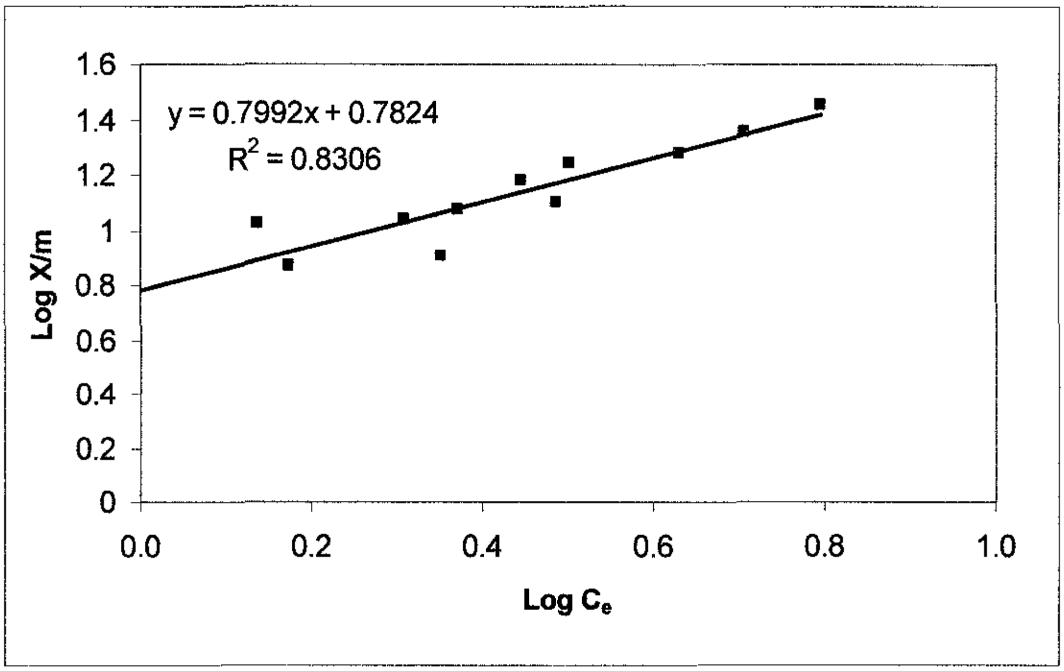

Figure 4. 5: Freundlich isotherm for adsorption of zinc on coconut coir carbon; 10 mg/l zinc; pH 6

Table 4. 1: Intercept and slope values of Freundlich isotherm for coconut coir carbon

Slope 1/n	**Intercept k**	**Coefficient of Determination, R^2**
0.7992	6.05	0.8306

The value of Freundlich constant, *n* was 1.42. According to Rao and Bhole, (2001) and Raji et al., (1997), adsorption is favorable for system which has n value in the range of 1 to 10. Values of *n* and *K* were comparable to those in the literature (Kaya and Oren, 2005 and Al-Duri et al., 1998).

4.5.2 Langmuir Isotherm

The uptake of zinc by coconut coir carbon was also evaluated using the Langmuir equation (2).

$$\frac{Ce}{Qe}=\frac{1}{Xmk}+\frac{Ce}{Xm} \qquad (2)$$

The data was taken from the results if varying adsorbent dose from 0.2 g/l to 1.4 g/l (Figure 4.3). This plot is for initial concentration of 10 mg/l and contact time of three hours. As shown in figure below, the straight line nature of the plot indicates that the adsorption follows Langmuir type.

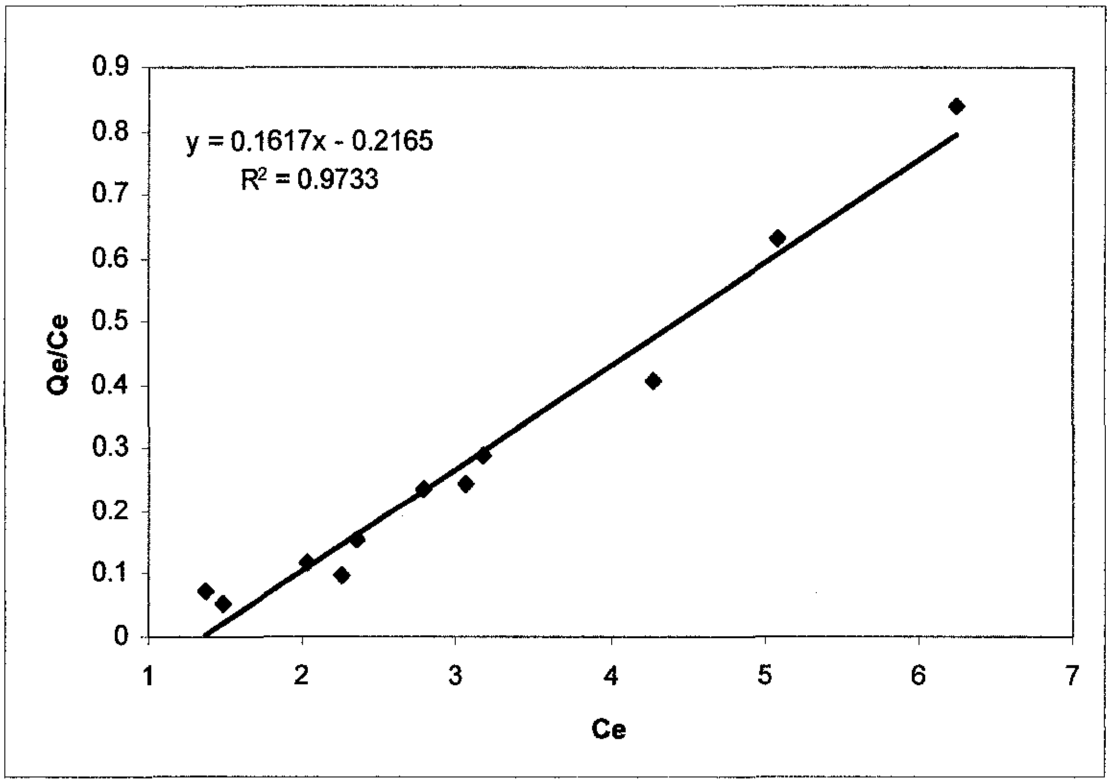

Figure 4. 6: Langmuir isotherm for adsorption of zinc on coconut coir carbon

Figure 4.6 shows the Langmuir adsoption isotherm. The langmuir maximum capacity X_m was 6.184 and this value is comparable to Al-Duri et al., (1998).

Table 4. 2: Langmuir maximum capacity of Langmuir isotherm for zinc adsorption on coconut coir carbon

Langmuir maximum capacity X_m	Coefficient of Determination, R^2
6.184	0.9733

Table 4.1 and 4.2 show the applicability of both Freundlich and Langmuir adsorption isotherm models to the adsorption of zinc by coconut coir carbon. It is suggested that Langmuir adsorption isotherm was being more appropriate for describing the adsorption based on coefficient of determination value.

4.6 Kinetics of adsorption

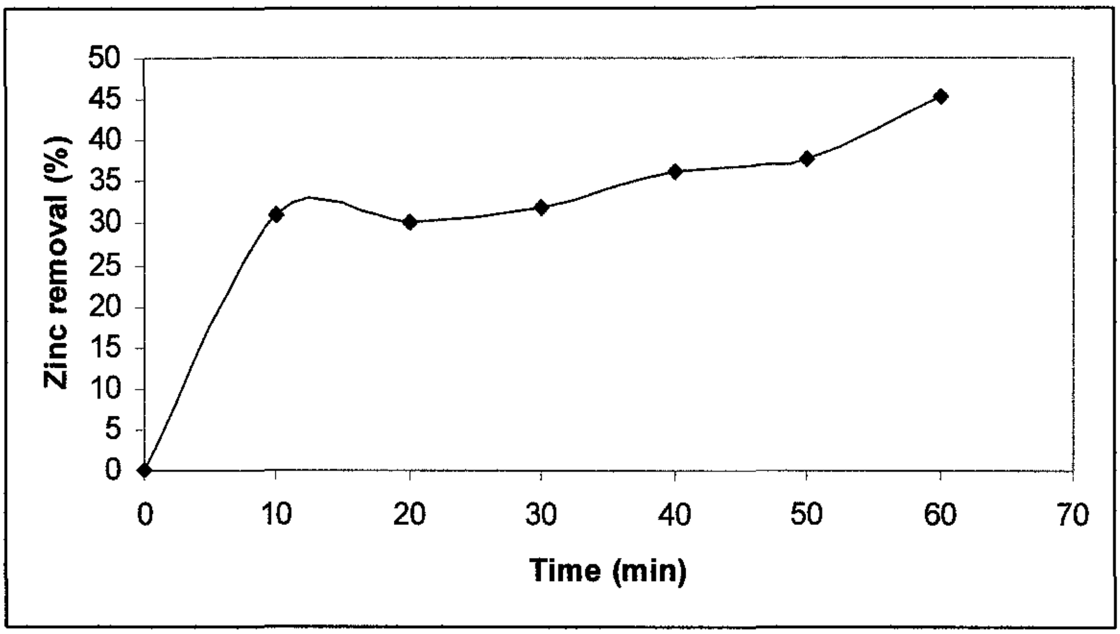

Figure 4.7: Zinc removal versus contact time (minutes); 10mg/l zinc; 1g/l adsorbent; pH 6

Another test was conducted to obtain data for the adsorption kinetics. The test was conducted for contact time less than the equilibrium contact time which is two hours. Zinc removal is increasing as the time increases as shown in Figure 4.7. The data obtained was then tested against both Lagergren first order and second order kinetics.

4.6.1 First Order Kinetic

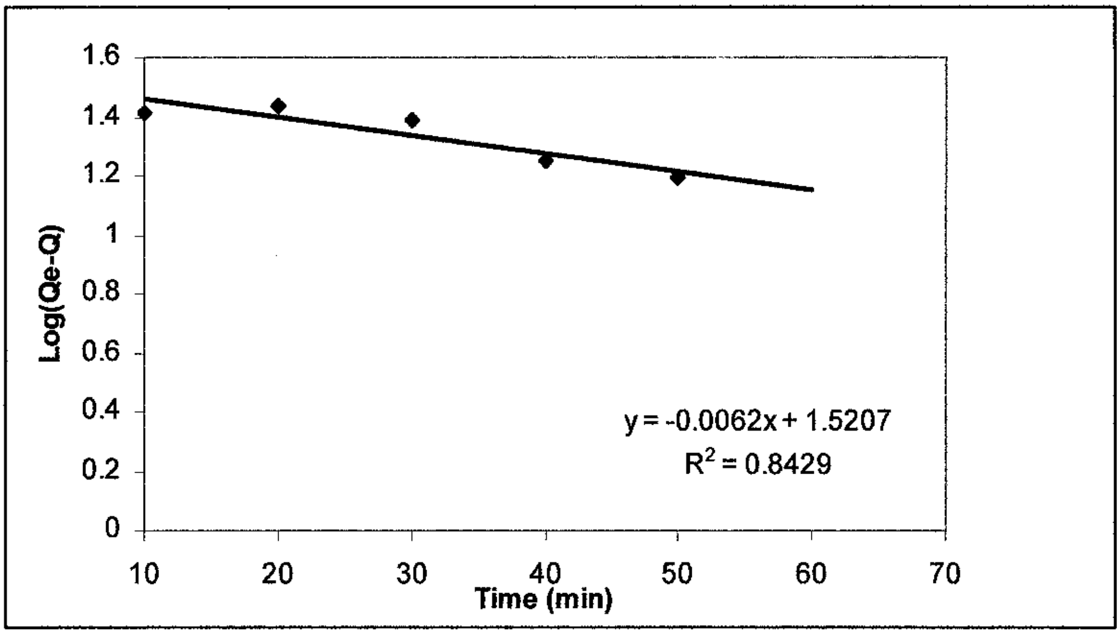

Figure 4. 8: Lagergren plot for the adsorption of zinc on coconut coir carbon (first order)

The straight line nature of the plot confirms the adherence to Lagergren equation (2) as shown in Figure 4.8.

$$Log(Qe - Q) = LogQe - \left(\frac{Kad}{2.303}\right)t \qquad (2)$$

The rate constants K_{ad} was calculated from the slope of the linear plot. The value of adsorption rate constant was 1.42 x 10^{-2} min^{-1}. This value is comparable to the values in the literature (Manju et al., 1998).

4.6.2 Second Order Kinetic

Figure 4.9 shows the data plotted into second order model. The pseudo-second order kinetic equation is given by

$$\frac{t}{Qt} = \frac{1}{2kQe2} + \frac{t}{Qe} \qquad (3)$$

The initial rate of adsorption, h is given by

$$h = 2kQe^2 \qquad (4)$$

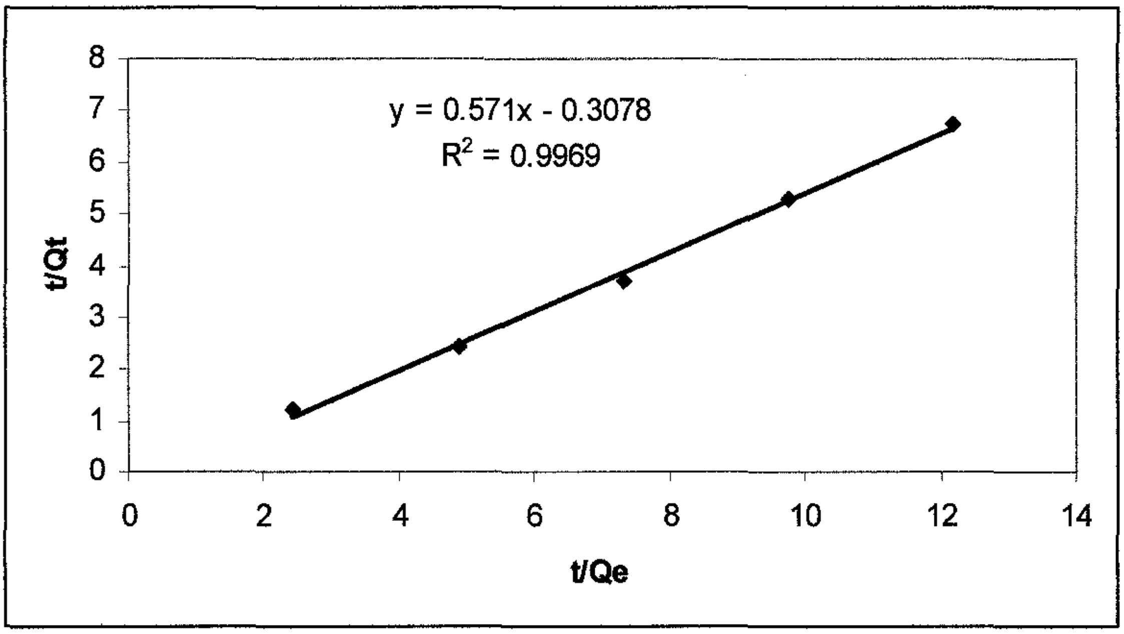

Figure 4. 9: Pseudo- second order plot for the adsorption of zinc on coconut coir carbon

The initial rate of adsorption value, h was 1.75 mg g^{-1} min^{-1}. This value is comparable to the values in the literature (Al-Duri et al., 1998).

Table 4. 3: Comparison of the applicability of the first and second order kinetic models

	First order	**Second order**
Coefficient of determination, R^2	0.8429	0.9969

Table 4.3 shows the applicability of both first order and second order kinetic models to the adsorption of zinc by coconut coir carbon. It is suggested that pseudo second order equation is being more appropriate for describing the adsorption.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Batch study results show that the coconut coir carbon has the capacity to adsorb significant amount of zinc from water. From the study, it is concluded that the adsorption of zinc by coconut coir carbon depends on the contact time, initial zinc concentration, pH of solution and the adsorbent dosage as follows;

1. The optimum contact time of the batch adsorption is three hours
2. Higher initial concentration of zinc will result in lower maximum adsorption
3. pH6 is the optimum pH for adsorption
4. The adsorption was found to follow Langmuir isotherm with Langmuir maximum capacity, X_m of 6.184
5. The adsorption followed pseudo second order kinetics with initial rate of 1.75 mg g^{-1} min^{-1}

It is also concluded that coconut coir carbon have a potential in adsorption capacity and can be used for wastewater treatment. The utilization of coconut coir carbon as the adsorbent will involve less capital cost and also efficient and feasible for small scale industries.

5.2 Recommendations

Industrial Wastewater

The entire study is conducted using synthetic zinc solution to enable parameters to be varied and ensures uniformity throughout the experiment. However, further studies using industrial waste water containing metals are recommended to enhance the understanding on metal removal method using adsorption.

Column and Desorption Studies

It is also recommended to evaluate the efficiency of coconut coir carbon by column studies. The volume of wastewater to be treated is usually large, thus continuous flow systems are preferred to evaluate zinc adsorption. Besides, desorption studies should also be conducted. The process of adsorption of zinc and regeneration of carbon is repeated until the carbon is fully exhausted.

Other Heavy Metals

In order to maximize the usage of coconut coir carbon in the wastewater treatment, the capacity of coconut coir carbon to adsorb other heavy metals that exist in wastewater such as cadmium and lead should be investigated.

REFERENCE

Al-Duri B., Forster C.F., Quek S.Y. and Wase D.A.J. (1998) Coir as Biosorbent of Copper and Lead. *Trans IChemE,* vol **76**: part B 50-54

Cimino G., Passerini A., and Toscano G. (2000) Removal of Toxic Cations and Cr(VI) from Aqueous Solution by Hazelnut Shell. *Water Research.* **34 (11):** 2955, As cited by Santhy and Selvapathy (2004)

Farrah, H., Hatton D., and Pickering W. F.,(1980) Affinity of Metal Ions for Clay Surfaces as sited by by Al-Duri *et. al.* (1998)

Forster C.F. and Wase D.A.J. (1997) Biosorbent for Metal Ions (Taylor and Francis, London) as cited by Al-Duri *et. al.* (1998)

Gupta V.K. and Ali I. (2000) Utilisation of Bagasse Fly Ash (A Sugar Industry Waste) For the Removal of Copper and Zinc from Wastewater, *Separation and Purification Technology* **18:** 131–140

Hasan S., Hashim M. A., and Gupta B. S., (1999) Adsorption of Ni(SO)4 on Malaysian Rubber-Wood Ash, *Bioresource Technology* **72**: 153-158

Huang J. P., Huang C. P., and Morehart A. L., (1991) Removal of Heavy Metals by Fungal Adsorption as cited by Al-Duri *et* al. (1998)

Interim Water Quality Standards for Malaysia, *Department of Environment (2005)* <http://www.doe.gov.my>

Kaya A. and Oren A.H. (2005) Adsorption of Zinc from Aqueous Solution to Bentonite. *Journal of Hazardous Material,* **B125**: 183-189

Kvech S. and Tull E. (1997) Activated Carbon, Civ. Eng. Dept, Virginia Tech, <ewr.cee.vt.edu/environmental/teach/wtprimer/carbon/sketcarb.html>

Metcalf and Eddy, Inc (2004) Wastewater Engineering Treatment and Reuse, Fourth Edition, McGraw-Hill

Namasivayam C. and Sureshkumar M.V. (2007) Removal of Chromium (VI) from Water and Wastewater using Surfactant Modified Coconut Coir Pith as a Biosorbent *Bioresource Technology*, **doi:10.1016/j.biortech**.2007.05.023

Raji C. and T.S. Anirudhan (1997) Chromium (VI) adsorption by sawdust: Kinetics and equilibrium , *Indian Journal of Chemical Technology*, **4**: 228-236

Rao M. and A.G. Bhole (2001) Chromium Removal by Adsorption Using Fly Ash and Bagasse, *Journal of Indian Water Works Association*, **XXXIII (1)**, 97-100

Santhy K. and Selvapathy P. (2004) Removal of Heavy Metals from Wastewater by Adsoprtion on Coir Pith Activated Carbon. *Separation Science and Technology*, **39**:3331-3351

Srivastava V.C., Mall I.D. and Mishra I.M. (2007) Removal of Cadmium (II) and Zinc (II) Metal Ions from Binary Aqueous Solution by Rice Husk Ash. *Colloids and Surfaces A: Physicochemical Engineering Aspects* **doi:10.1016/j.colsurfa**.2007.06.048

Sumathi K.M.S., Mahimairaja S. and Naidu R. (2005) Use of Low-Cost Biological Wastes and Vermiculite for Removal of Chromium From Tannery Effluent, *Bioresource Technology* **96**: 309–316

Treybal E. R.(1981) Mass Transfer Operations, 3rd edition, McGraw Hill International editions, Chemical Engineering Series, Singapore

Wan Ngah W.S. and Hanafiah M.A.K.M. (2007) Removal of Heavy Metal Ions from Wastewater by Chemically modified plant wastes as adsorbents: A review *Bioresource Technology*. **doi:10.1016/j.biortech**.2007.06.011

Wong K. K., Lee C. K., Low K. S., Haron M. J., (2003) Removal of Cu and Pb by Tartaric Acid Modified Rice Hush Ash from Aqueous Solution, *Chemosphere* **50**: 23-28

APPENDICES

Appendix A: Results for effect of contact time

Retrieve time(hour)	Initial concentration (mg/l)	Average final concentration (mg/l)	Zinc removal (%)
10 mg/l			
1	10.1	5.6	45
2	10.1	3.8	63
3	10.1	3.8	63
4	10.1	3.6	65
5	10.1	3.6	65
50 mg/l			
1	50	34	32
2	50	30	39
3	50	29	41
4	50	29	41
5	50	29	41
100 mg/l			
1	100	81	19
2	100	77	23
3	100	76	24
4	100	75	25
5	100	75	25

Appendix B: Results for effect of pH

pH	Initial concentration (mg/l)	Final concentration (mg/l)	Average final concentration (mg/l)	Zinc removal %
3	10.1	5.6	5.57	44.88
	10.1	5.7		
	10.1	5.4		
4	10.1	1.4	1.20	88.11
	10.1	1.2		
	10.1	1.0		
5	10.1	1.2	1.17	88.44
	10.1	1.0		
	10.1	1.3		
6	10.1	0.6	0.60	94.05
	10.1	0.8		
	10.1	0.4		
7	10.1	0.9	0.93	90.75
	10.1	1.0		
	10.1	0.9		
8	10.1	5.7	5.77	42.90
	10.1	5.8		
	10.1	5.8		
9	10.1	7.0	6.93	31.35
	10.1	6.9		
	10.1	6.9		
10	10.1	6.3	6.37	36.96
	10.1	6.5		
	10.1	6.3		

Appendix C: Results of the effect of adsorbent dose

Sample number	Adsorbent dose (g/l)	Removal (%)	Remaining (%)	Equilibrium Concentration C_e (mg/l)	Uptake X(mg/g)	X/m	Log x/m	Log C_e	Q_e/C_e (g/l)	C_e/Q_e
1	1.4	87.49	12.51	1.49	10.41	7.44	0.87	0.17	6.00	0.1666
2	1.2	81.10	18.90	2.25	9.65	8.04	0.91	0.35	7.00	0.1428
3	1.0	88.50	11.50	1.37	10.53	10.53	1.02	0.14	8.40	0.119
4	0.9	82.92	17.08	2.03	9.87	10.96	1.04	0.31	9.34	0.1071
5	0.8	80.18	19.82	2.36	9.54	11.93	1.08	0.37	10.50	0.0952
6	0.7	74.25	25.75	3.06	8.84	12.62	1.10	0.49	12.00	0.0833
7	0.6	76.53	23.47	2.79	9.11	15.18	1.18	0.45	14.01	0.0714
8	0.5	73.33	26.67	3.17	8.73	17.45	1.24	0.50	16.81	0.0595
9	0.4	64.08	35.92	4.27	7.63	19.06	1.28	0.63	21.01	0.0476
10	0.3	57.28	42.72	5.08	6.82	22.72	1.36	0.71	28.01	0.0357
11	0.2	47.57	52.43	6.24	5.66	28.31	1.45	0.80	42.02	0.0238
12	0	0	100.00	11.9	0.00	-	-	-	-	-

Appendix D : Results of the Effect of Contact Time (10-60 minutes) on Zinc Adsorption (for First Order Kinetics)

Sample number	Time (min)	Final concentration Q (mg/l)	Q_e-Q	log(Q_e-Q)
1	10	8.2	4.1	1.41
2	20	8.3	4.2	1.44
3	30	8.1	4.0	1.39
4	40	7.6	3.5	1.25
5	50	7.4	3.3	1.19
6	60	6.5	2.4	0.88

Appendix E: Results of the Effect of Contact Time (10-60 minutes) on Zinc Adsorption (for Second Order Kinetics)

Sample number	Time t (min)	Final concentration Q_t (mg/l)	t/ Q_t	t/Q_e
1	10	8.2	1.219512	2.439024
2	20	8.3	2.409639	4.878049
3	30	8.1	3.703704	7.317073
4	40	7.6	5.263158	9.756098
5	50	7.4	6.756757	12.19512
6	60	6.5		

Equilibrium concentration at time 120 minutes=4.1 mg/l

Appendix F: Tools and Equipment used

No	Equipment	Frequency of use (hours per week)
1	DR2800 Spectrophotometer	16
2	Mechanical Shaker	16
3	Analytical Balance	2
4	Shaker Bottle	16
5	Measurement Cylinder	1
6	Oven	72
7	Nitrogen Atmosphere Furnace	12
8	pH meter	4

Appendix G: Chemical and Material Required

No	Chemicals/Materials	Quantity
1	Coconut coir	3 kg
2	Distilled water	Excess
3	Zn^{2+} solution	8000 mL
4	1M HCl	50 mL
5	0.1M NaOH	1000 mL
6	KOH pallets	50 g

Appendix H: Maximum Effluent Parameters Limits (Standard A and Standard B) Environmental Quality (Sewage and Industrial Effluents)

No	Parameters	Units	Standard	
			A	B
1	Temperature	°C	40	40
2	pH	-	6.0-9.0	5.5-9.0
3	BOD5 @ 20oC	mg/l	20	50
4	COD	mg/l	50	100
5	Suspended Solids	mg/l	50	100
6	Mercury	mg/l	0.005	0.05
7	Cadmium	mg/l	0.01	0.02
8	Chromium, Hexalent	mg/l	0.05	0.05
9	Arsenic	mg/l	0.05	0.10
10	Cyanide	mg/l	0.05	0.10
11	Lead	mg/l	0.1	0.50
12	Chromium, Trivalent	mg/l	0.2	1.0
13	Copper	mg/l	0.2	1.0
14	Manganese	mg/l	0.2	1.0
15	Nickel	mg/l	0.2	1.0
16	Tin	mg/l	0.2	1.0
17	Zinc	mg/l	1.0	1.0
18	Boron	mg/l	1.0	4.0
19	Iron	mg/l	1.0	5.0
20	Phenol	mg/l	0.001	1.0
21	Free Chlorine	mg/l	1.0	2.0
22	Sulphide	mg/l	0.5	0.5
23	Oil and Grease	mg/l	Not detectable	10.0

*Standard A for discharge upstream of drinking water take-off

*Standard B for inland waters

Appendix I: Values of Freundlich Isotherm for other studies

No	Researcher	Material used	Metal investigated	Values	
				K	n
1	Kaya and Oren (2005)	Bentonite	Zinc	2.682	0.47
2	Al-Duri et al. (1998)	Coir	Lead	20.62	0.19
			Copper	4.16	0.26

Appendix J: Values of Langmuir Isotherm for other studies

No	Researcher	Material used	Metal investigated	Values
				Xm
1	Farrah et al (1980)	Kaolin clay	Lead	3.9
2	Al-Duri et al. (1998)	Coir	Lead	48.5
			Copper	19.3
3	Huang et al (1991)	*Aspergillus Orysae*	Copper	6.9

Appendix K: Values of First Order Kinetics and Second Order Constant for other studies

No	Researcher	Material used	Metal investigated	Values	
				First Order K_{ad}	Second Order *h*
1	Al-Duri et al. (1998)	Coir	Copper	N/A	1.8
			Lead	N/A	2.9
3	Manju et al (1991)	Coconut Husk Carbon	Arsenic	1.29×10^{-2}	N/A