

**Adsorption of Zinc by Using Combusted Palm Oil Kernel**

by

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Dissertation submitted in partial fulfillment of  
the requirements for  
Bachelor of Civil Engineering (Hons.)

**JUNE 2007**

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**CERTIFICATION OF APPROVAL**

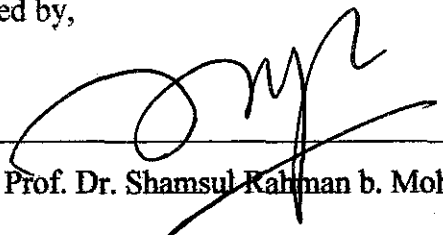
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A project dissertation submitted to  
**Civil Engineering Programme**  
**Universiti Teknologi PETRONAS**  
in partial fulfilment of the requirements for the  
**BACHELOR OF ENGINEERING (Hons)**  
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Approved by,



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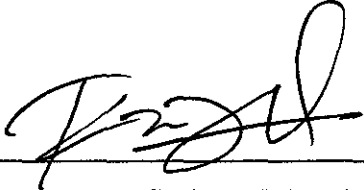
(Assoc. Prof. Dr. Shamsul Rahman b. Mohamed Kutty)

**UNIVERSITI TEKNOLOGI PETRONAS**  
**TRONOH, PERAK**

June 2007

## **CERTIFICATION OF ORIGINALITY**

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



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**MOHAMAD FAISAL BIN AZIZ**

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*In the name of Allah, The most gracious and The most merciful...*

All praises only for Allah. He provided me the real strength and blessed me with a little knowledge in accomplishing the project.

The appreciation is also meant to my beloved parent and family for their trust and endless support. They are my greatest motivation for me to go smoothly.

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August 1<sup>st</sup>, 2007

## ABSTRACT

The report is prepared to provide readers information regarding the experiment of adsorption of zinc by using combusted palm oil kernel. The presence of heavy metals in water causes harm since they are classified as toxic. The objective of the experiment is to establish the optimum adsorbent dosage, the optimum adsorption period for the adsorption of zinc and the best adsorption isotherm model. The size of adsorbent was  $R_{425\mu m}$ . Zinc had been used during the experiment as heavy metals to be adsorbed by the adsorbent. The adsorbent dosages used were 25, 50, 100, and 200 mg, 25, 50, 75, and 100 mg, and 1000, 2000, 3000, and 4000 mg. The combusted palm oil kernels were supplied to every aqueous zinc solution sample. The concentrations were divided into two which were 10 and 100 ppm. All samples were shaken by orbital shaker with four different durations 1, 3, 6, and 24 hours. Only after the shaking processes completed, the final concentrations of aqueous zinc solution were measured by using HACH DR2800 Spectrophotometer. In the first trial of phase 1 with initial concentration of 11.45 mg/L, the optimum adsorbent dosage was 2000mg/L and the optimum adsorption period was 24 hours. In the second trial of phase 1 with initial concentration of 240mg/L, the optimum adsorbent dosage was 2000 mg/L and the optimum adsorption period was 24 hours. In the second trial of phase 1 with initial concentration of 141.33 mg/L, the optimum adsorbent dosage was 1000 mg/L and the optimum adsorption period was 6 hours. In the first trial of phase 2 with initial concentration of 10 mg/L, the optimum adsorbent dosage was 2000 mg/L and the optimum adsorption period was 3 hours. In the first trial of phase 2 with the initial concentration of 110 mg/L, the optimum adsorbent dosage was 2000 mg/L and the optimum adsorption period was 24 hours. In the second trial of phase 2 with the initial concentration of 10 mg/L, the optimum adsorption period was 6 hours and the optimum adsorbent dosage was 40000 mg/L. In conclusion, the higher the adsorbent dosage was used, the higher the percentage removal. A good plot of the adsorption isotherm depended on the degree of consistency of the adsorption model.

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# CHAPTER 1

## INTRODUCTION

### 1.1 BACKGROUND OF STUDY

Adsorption is the process of accumulating substances that are in solution on a suitable interface (Metcalf and Eddy, 2004). The adsorption of heavy metal is widely studied throughout the globe in order to enhance the treatment process of wastewater. In a continuing search for the adsorbent, various lignocellulosic materials or agricultural waste such as coconut shell, rice husks, saw dust, and wheat straw were used (Srivastasa *et al.*, 1987). These materials were pyrolysed or carbonized in an inert atmosphere in order to remove volatile organic constituents, leaving behind a highly porous carbonaceous residue, followed by either chemical, steam or gas activation for removal of the pollutant. The presence of heavy metals in the wastewater is due to the industrial processes such as coating of metal surfaces in the electroplating industry and leather tanning. Natural resources that are available in the form of waste from agricultural operations might be used as low cost adsorbent. A number of adsorbent materials have been studied for their capacity to remove heavy metals including activated carbon, activated alumina, ion exchange resins, crushed coals etc. (Muhammad *et al.*, 1998) Adsorption by activated carbon which obtained from the combustion of palm oil kernel is identified as one of techniques for removing heavy metal from wastewater. The adsorption capability is due to the surface complex formation between the metal ions and the acidic surface functional groups such as carboxylic, hydroxyl, and lactone, which have a high affinity for metal ions. Activated carbon is very effective in removing heavy metals, however it is readily soluble under extreme pH conditions (Huang *et al.*, 1989). Numerous attempts have been done to correlate the adsorption capacity with the surface area of the activated carbon. However, very limited conclusion could be made. Hence, the adsorption might be correlated with the chemical nature of the carbon surface.

## **1.2 PROBLEM STATEMENT**

The presence of heavy metals in wastewater causes harm when released to the atmosphere since they are classified as toxic. The wastewater which contaminated with heavy metal could seep through the groundwater sources and contaminating stream flow. According to the World Health Organization, the metals of most immediate concern are cadmium, chromium, cobalt copper, lead, nickel, mercury and zinc. Since stream flow is a prime water source in Malaysia, hence it will affect human's health during water consumption especially drinking. The abundance of agricultural of biomass also creates problems of disposing it.

## **1.3 OBJECTIVE AND SCOPE OF STUDY**

The objective of this research is to study the influence of modified adsorbent dosage in removing zinc. Different dosages would affect different adsorption capacity. The dosages would be varied after several adsorption processes. Different concentration of zinc might need different dosages.

The research is meant to establish the relationship between percentage removal and adsorbent dosage. Theoretically, the higher the adsorbent dosage applied the higher the adsorption capacity. Hence, the correlation is very important in this research.

Adsorption isotherm also is very important. This research would analyze adsorption isotherms for every adsorption model. Hence, the adsorption capacity of palm oil kernel would be identified clearly from the derived variables in the isotherm.

## CHAPTER 2

### LITERATURE REVIEW

#### 2.1 ZINC

Zinc is a chemical element in the periodic table that has the symbol **Zn** and atomic number 30. In some historical and sculptural contexts, it is known as spelter. Zinc is a moderately-reactive bluish-white metal that tarnishes in moist air and burns in air with a bright greenish flame, giving off plumes of zinc oxide. It reacts with acids, alkalis and other non-metals. If not completely pure, zinc reacts with dilute acids to release hydrogen. The one common oxidation state of zinc is +2. From 100 °C to 210 °C zinc metal is malleable and can easily be beaten into various shapes. Above 210 °C, the metal becomes brittle and will be pulverized by beating. (*Wikipedia*)

##### 2.1.1 Heavy Metals Contamination

Heavy metals contamination is one of the major issues in wastewater treatment process. Since several types of heavy metal are classified as toxic, hence the removal of heavy metal shall be a must in any wastewater treatment process. Generally, the contamination of heavy metals in wastewater is from industrial activity. According to Zeljka (2000), the effluent from metal finishing process may contain up to 10 mg/L of copper chromium nickel and zinc.

Electroplating, leather tanning, cement dyeing, metal processing, and wood preservatives contribute to the contamination of heavy metals in streams and major drains (Nomanbhay *et al*, 2004). Even worst, it can penetrate into the ground and seep through the ground water sources. Thus, the hazard of toxicity is exposed to the human since the streamflow is the prime source of water supply in Malaysia.

There are several applications of heavy metal removal in wastewater treatment process (Huang *et al.*, 1989). Some might be expensive and some might create drawbacks. The

applications are precipitation, ion exchange, Reverse Osmosis (RO), electrodialysis, and adsorption.

Precipitation causes problem due to the sludge production. The precipitation is basically done by coagulation process. Disposal of sludge needs a good planning which will consume an expensive budget. Ion exchange is also an expensive method. It is classified as tertiary treatment. Modern facilities meant for removal of heavy metals in ion exchange need to be installed.

Furthermore, ion exchange is site specific. Adsorption process is found as a very practical approach to remove heavy metals. There is a wide range of adsorbent that can be found applied in wastewater treatment process. Heavy metal adsorption by using activated carbon is one of those. The existence of some functional groups might be associated with the capability of carbon to adsorb heavy metals. However, it is only a part of adsorption theory.

### **2.1.2 Impact of Heavy Metals**

Many metallic elements play important roles in the function of living organisms. Living organism require trace amount of some heavy metals, including cobalt, copper, iron manganese, molybdenum, vanadium, strontium, and zinc. They not only constitute a nutritional requirement, but also a physiological role. However, overabundance of the essential elements and their substitution by nonessential ones can cause toxicity symptoms (Kenish, 1992). Non-essential heavy metals of particular concern to surface water systems are cadmium, chromium, mercury, lead, arsenic and antimony. Assimilation of metals takes place in the microbial world as well and in plants, these elements tend to get concentrated as they progress through the food chain. Excessive amounts of a metal species along this route lead to toxicity symptoms, to disorders in cellular functions and death (Volesky, 1990).

## 2.2 WHAT IS CARBON?

Carbon is recognized as non-metallic element that available in all living things (organic) and also available largely in inorganic compounds. The word carbon was originated from Latin, *carbo*, while French named it as *charbon* which both mean charcoal. In German and Dutch, carbon is called as *kohlenstoff* and *koolstof* respectively, both connote the as “coal-stuff”. In the early age, carbon was found by burning organic material in insufficient oxygen. The common known carbon is in the form of charcoal. It has been known since ancient times and it has a variety of applications. Carbon is a basic element in the organic chemistry and its ability to bind with other element has formed a million of compounds. (*Wikipedia*)

### 2.2.1 Carbon Surface Chemistry

Most of the researchers believe that the ability of carbon to adsorb organic and inorganic matters is due to the presence of some functional on its surface. Smith (1863) hypothesized that a chemical change will occur when carbon react with oxygen. While Reed and Wheeler (1912, 1913) explained that some oxygen-carbon complex(s) was formed when oxygen contacts carbon surfaces. Steenberg in 1944 proposed that the capability of carbon adsorb strong base is called L-type (acidic carbons) and those capable of adsorbing a strong acid be called H-type (basic carbons). L-type is treated under exposed oxygen with temperature 200°C to 500°C or solution oxidants during the activation process. H-type carbons are formed using activation methods that remove indigenous surface oxide groups. It can be obtained by heating the carbon by the presence of inert gas or vacuum and cooling to low temperature in the same environment.

### **2.2.2 Removal Mechanism**

Heavy metal removal could only happen under several phenomenons which are physical adsorption, chemisorption, hydrogen bonding, ion exchange, surface precipitation and filtration. Physical adsorption is the most common application in removing heavy metals and it is recognized as primary removal mechanism for organic adsorbates.

Chemisorption behaves more specific by involving the formation of covalent bond (electron sharing) between adsorbate and the carbon surface. Chemisorption is considered to be irreversible while physical adsorption is reversible. A long-range attractive force between the hydrogen atom of hydrated metal ions and a specific carbon surface site enable the adsorption to be happened. Hydrogen bond can be classified under chemisorption. However, covalent bonding is much stronger than hydrogen bond. Covalent bond is responsible to form a much stronger inner-sphere complex while hydrogen bonding will form outer-sphere complex. Ion exchange occurs when adsorbent and adsorbate possess opposite charges. Precipitation of metals on a surface is much easier than the formation of the same solid in solution. High concentration of metals and OH<sup>-</sup> in carbon pore volume can enhance metal removal.

## **2.3 ADSORPTION**

Adsorption process is found as a very practical approach to remove heavy metals. There is a wide range of adsorbent that can be found applied in wastewater treatment process. Heavy metal adsorption by using activated carbon is one of those. The existence of some functional groups might be associated with the capability of carbon to adsorb heavy metals. However, it is only a part of adsorption theory.

Adsorption is defined as a process of collecting substances in water onto a surface of solid. Another extended definition of adsorption is the process of accumulating substances that are in solution on a suitable interface (Metcalf and Eddy, 2004). When a liquid mixture is in contact with a microporous solid, adsorption of certain components in



the mixture takes place on the internal surface of the solid. There are several factors that affect the efficiency of adsorption.

There are two major processes happen during adsorption. Firstly is physisorption and secondly is chemisorption. The functional group which has high affinity to metals will adsorb the metal during physisorption. The physisorption will last until the equilibrium state. Time taken until the equilibrium state is called equilibrium time ( $t_e$ ) and the concentration at  $t_e$  is called equilibrium concentration ( $c_e$ ). The residual metal concentration which is not adsorbed during physisorption will be adsorbed by chemisorption process. The chemisorption process can be described as the intrapore diffusion of heavy metals into carbon molecule. This process is time consuming since its adsorption rate is relatively small.

There are some modification methods applicable in activating the carbon surface. The modification method can be physically and chemically. Typically, in physical modification, the carbon will be heated up until  $750^\circ\text{C}$  However with an insufficient supply of oxygen to sustain combustion. Then it is exposed to oxidizing gas such as steam and  $\text{CO}_2$  at high temperature in the range from  $800$  to  $900^\circ\text{C}$ . Second method of activation is by using chemicals. Formaldehyde, nitric acid ( $\text{HNO}_3$ ), and pH controlled solution which is combination of sulphuric acid ( $\text{H}_2\text{SO}_4$ ) and sodium hydroxide ( $\text{NaOH}$ ) are always used in chemical activation treatment. Typically, strong acid will be used in chemical treatment of carbon activation.

### **2.3.1 Adsorption Isotherm**

In developing the adsorption isotherm, the quantity of adsorbate that can be taken up by an adsorbent is a function of both the characteristics and concentration of adsorbate and the temperature. Generally, the amount of material absorbed is determined as a function of the concentration at a constant temperature, and the resulting function is called an adsorption isotherm (Metcalf and Eddy, 2004).

Equation that are often used to describe the experimental isotherm data were developed by Freundlich, Langmuir, and Brunauer, Emmet, and Teller (BET isotherm) (Shaw, 1966). Of the three, the Freundlich isotherm is used most commonly to describe the adsorption characteristics of the activated carbon used in water and wastewater treatment. Derived empirically in 1912, the Freundlich isotherm is defined as below:

$$x/m = K_f C_e^{1/n} \quad (\text{eq. 1})$$

where  $x/m$  = mass of adsorbate adsorbed per unit mass of adsorbent, mg adsorbate/g activated carbon

$K_f$  = Freundlich capacity factor, (mg adsorbate/g activated carbon) (L water/mg adsorbate)<sup>1/n</sup>

$C_e$  = equilibrium concentration of adsorbate in solution after adsorption, mg/L

$1/n$  = Freundlich intensity parameter

The constant can be written as:

$$\text{Log } (x/m) = \text{log } K_f + 1/n \text{ log } C_e \quad (\text{eq. 2})$$

Derived from rational consideration, the Langmuir adsorption isotherm is defined as:

$$x/m = abC_e / (1 + bC_e)$$

where  $x/m$  = mass of adsorbate adsorbed per unit mass of adsorbent, mg adsorbate/g activated carbon

$a, b$  = empirical constant

$C_e$  = equilibrium concentration of adsorbate in solution after adsorption, mg/L

## 2.4 EFFECT OF PH

The most common used method to remove soluble metal ions from solution is to precipitate the ion as a metal hydroxide. The process is readily automated and controlled by a simple pH controller. By raising the pH value of a solution with a common alkaline material such as lime, or sodium hydroxide the corresponding metallic hydroxide compounds become insoluble and precipitate from solution. Below is a metal hydroxide solubility curve showing the solubility of the common heavy metal ions and their respective solubility versus pH.

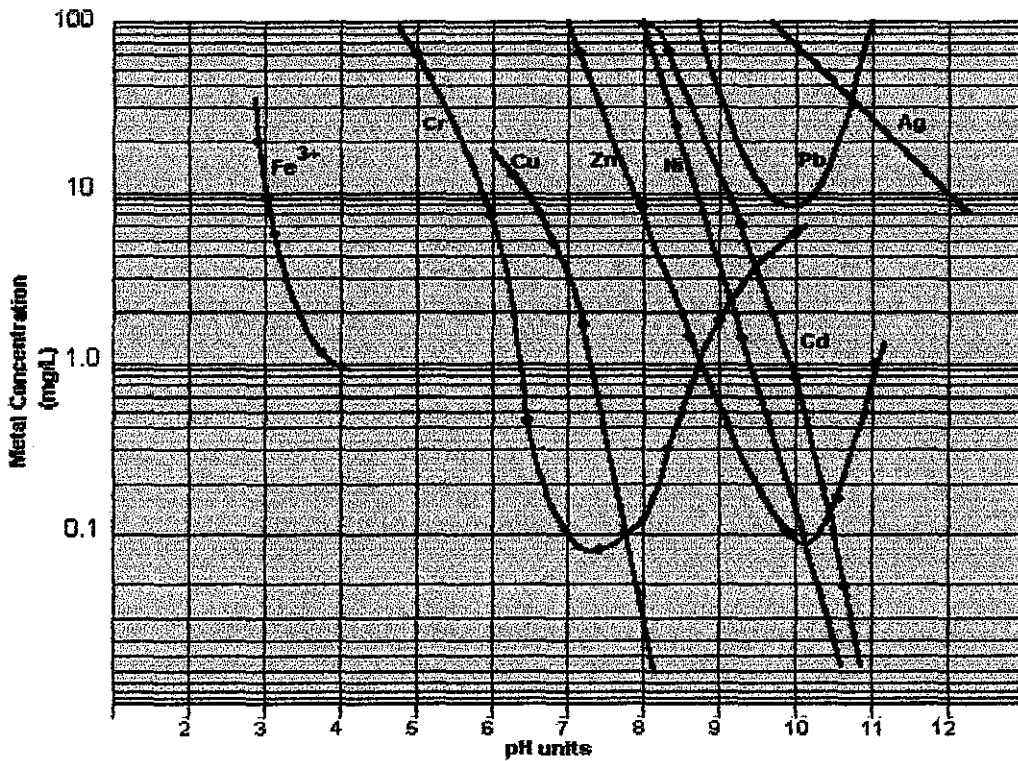


Figure 1 Solubility Curve of Various Heavy Metal Ions

Precipitation is unfavourable in this project. Hence, pH measurement is crucial to ensure precipitation would not happen. Specifically for zinc, pH 10 is a minimum pH for it to be precipitated.

## **CHAPTER 3**

### **METHOD & PROCEDURE**

#### **3.1 PREPARATION OF ADSORBENT**

Adsorbent used in this experiment was obtained from combusted palm oil kernel. It was grounded and sieved based on several sizes. The size used in this experiment was R425 $\mu$ m. R425 $\mu$ m is the size of combusted palm oil kernel particles that retained on sieve with openings of 425 $\mu$ m. The sizes below R425 $\mu$ m were too small and very difficult to handle in term of weighing and transferring. Hence, the most practical sized used was R425 $\mu$ m.

##### **3.1.1 Preparation of Aqueous Zinc Solution (Refer Appendix 1)**

Zinc Chloride ( $ZnCl_2$ ) was used for the preparation of aqueous zinc solution. Zinc chloride was the only source of zinc that available in the lab. In order to prepare 1000 mg/L of aqueous zinc solution, 2.084 gm of zinc chloride was diluted in 1000 ml of distilled water. 1000 mg/L of aqueous zinc solution was the stock solution. The stock solution was diluted to desired concentrations which were 100 mg/L and 10 mg/L. On the basis of 1000 ml, 10 ml of stock solution was diluted with 990 ml of distilled water in order to obtain 10 mg/L of zinc solution. While, 100 ml of stock solution was added with 900 ml of distilled water in order to obtain 100 mg/L of zinc solution.

During preparation of aqueous zinc solution, same apparatus would be used repetitively. Hence, every apparatus should be washed and rinsed carefully to avoid any influences of residual zinc to the desired concentration of new aqueous zinc solution.

## **3.2 ZINC ADSORPTION PROCESS**

### **3.2.1 First Phase**

During the first phase of project, two trials had been done. Both trials differed by their adsorbent dosages. The adsorbent dosages in the first trial were 25, 50, 100, and 200 mg. The adsorbent dosages used in the second trial were 25, 50, 75, and 100 mg.

Same adsorption period, (t) were used for both trials. The adsorption periods were varied at 1, 3, 6, and 24 hours. Initial concentrations  $C_0$  were also varied in this experiment. The initial concentrations  $C_0$  used in this experiment were 100 and 10 mg/L.

In the adsorption process, 100 ml of aqueous zinc solution was pipette into BOD bottle. The concentration of aqueous zinc solution was on 100 or 10 mg/L basis. Every bottle was dosed with adsorbent based on its trial (first or second trial). Each dosage was prepared with three same samples which meant for average reading.

Next, all the samples were put onto the orbital shaker. The speed of the orbital shaker was 150 rpm. The speed of the orbital shaker should be monitored. Increase in speed would lead to inefficiency of adsorption. The adsorbent would tend to flocculate at the upper surface of the aqueous zinc solution.

After the adsorption period elapsed, the samples were ready to be filtered out from aqueous zinc solution. Vacuum filter was used in this process. The presence of adsorbent during zinc content test would influent the readings.

### **3.2.2 Second Phase**

In the second phase of project, the adsorbent dosages were modified to 1000 mg, 2000 mg, 3000 mg and 4000 mg. This was due to insufficient dosages in zinc adsorption process during the first stage. The rest of the steps were same as the first phase of project.

### **3.3 MEASUREMENT OF ZINC CONCENTRATION**

Throughout the experiment, the only equipment used for zinc content test was spectrophotometer HACH DR 2800. All the procedures of zinc test were based on the supplied manual by vendor. Prior to performing the zinc test, the sample had to be diluted to the specific range (0.01 to 3.00 mg/L). In this experiment, the sample was diluted to 1 mg/L from the original zinc aqueous solution.

Initially, 20 ml of diluted zinc solution was pipette into sample cell. Normal pipette was used for the accuracy of measurement. The sample supposedly pipette into 25 ml graduated mixing cylinder. However, sample cell was used due to the unavailability of graduated mixing cylinder. After pouring the zinc solution into sample cell, the sample was added with ZincoVer 5 Reagent Powder and was shaken until the sample turned blue (based on zinc concentration). 10 ml of the shaken sample was poured into a square sample cell. This sample was meant for blank solution.

The next step was the remaining sample was added with 0.5 ml of cyclohexanone and was shaken for 30 seconds. The cyclohexanone was dropped by using prepared plastic dropper. Right after the addition of cyclohexanone, the sample was undergone for 3 minutes of reaction time. During this period, the sample cell for the first 10 ml sample was wiped and inserted into spectrophotometer with the filling line facing reader light. After 3 minutes of reaction time elapsed, ZERO button was pressed and the spectrophotometer would read blank solution and gave 0.00 mg/L reading.

Finally, the prepared sample was wiped and inserted into spectrophotometer and reading was taken. The sample cell was wiped by using special tissue meant for delicate works. Every cell sample was washed and rinsed carefully in order to avoid any inconsistencies during result reading. The reading of zinc concentration was multiplied by dilution factor in order to obtain the actual concentration of the sample.

### 3.4 RESULT ANALYSIS

After obtaining the result from zinc adsorption process, equilibrium concentrations  $C_e$  were calculated. Based on the equilibrium concentration, several graphs should be plotted which were residual zinc vs. adsorbent dosage, residual zinc vs. adsorption time, percentage removal vs. adsorbent dosage, and percentage removal vs. time. The plotted graphs provided the effective adsorbent dosage and adsorption period in the adsorption of zinc.

Instead of plotting graphs, the most important adsorption isotherms which were Freundlich and Langmuir were determined. In Freundlich Isotherm, graph  $\text{Log } x/m$  vs.  $\text{Log } C_e$  was plotted and three important parameters were identified. The parameters were  $R^2$ ,  $1/n$  and  $K_f$ . Those parameters were core determinants for the effectiveness of the adsorbent used.

In Langmuir, graph  $1/(x/m)$  vs.  $1/C_e$  was plotted. Mole fraction of zinc in zinc chloride,  $x$  were compared with  $R^2$  value from the graph.

# CHAPTER 4

## RESULTS & DISCUSSIONS

### 4.1 PHASE 1

During the first phase of project, two trials of zinc adsorption had been done. Both trials were differed in adsorbent dosages. Adsorbent dosages on the first trial were 25, 50, 100 and 200 mg. On the second trial, the dosages were modified to 25, 50, 75, and 100 mg. The results of the trials will be elaborated further in this chapter.

#### 4.1.1 First Trial

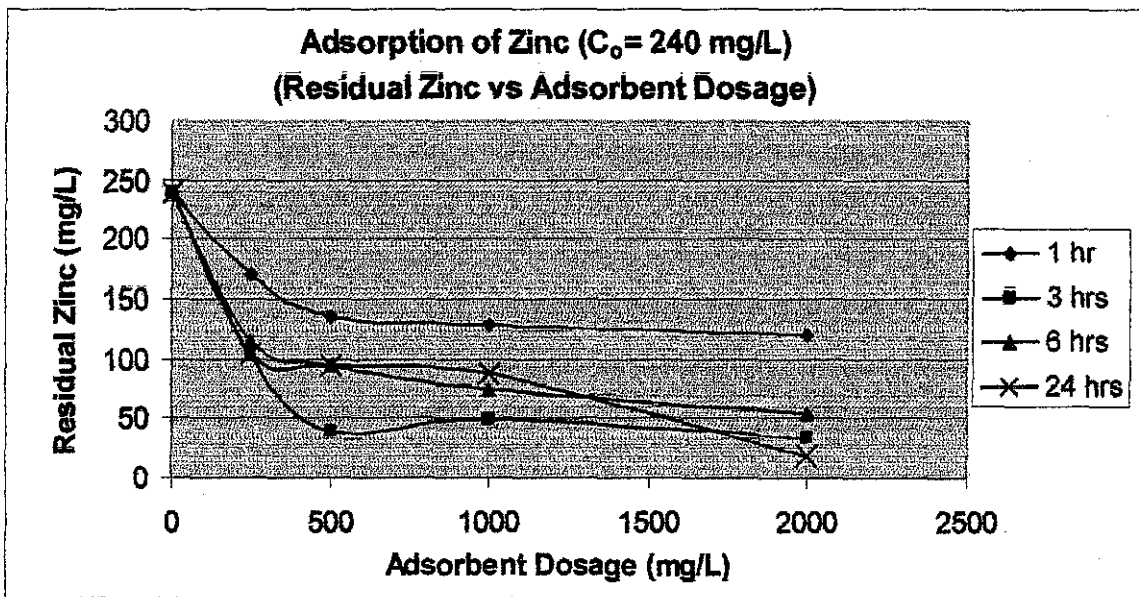


Figure 2: Graph Residual Zinc vs. Adsorbent Dosage ( $C_0 = 240$  mg/L)

Based on Figure 1, the 1 hour period showed a good adsorption curve. The adsorptions were higher at 25 and 50 mg of adsorbent dosage and about constant from 50 to 200 mg of adsorbent dosage. In 3 hour of adsorption, the curve was fluctuated. The residual zinc at 50mg of adsorbent dosage was 39.5 mg/L and the residual zinc at 100 mg of adsorbent dosage was 48.67 mg/L. The residual zinc for the next 100 mg of adsorbent dosage was



33.5 mg/L. The adsorption curve for 6-hour period showed a good trend. The amount of residual zinc was constantly decreased. In 24-hour curve, the adsorption between 50 to 100 mg of adsorbent dosage was not much changed. Residual zinc at 50 mg and 100 mg of adsorbent was 94.5 mg/L and 87 mg/L respectively. The lowest residual zinc obtained was at 24-hour of adsorption which was 18 mg/L.

Actually, the intended initial concentration for aqueous zinc solution was 100mg/L. However, due to several errors during the preparation of the solution, the concentration had changed to 240 mg/L. The error was caused by the dilution process of stock solution. The concentration of stock solution was 1000 mg/L. During the zinc content test, the diluted solution was diluted again directly to 1 mg/L. There were no transitions (100 to 10 to 1 mg/L of zinc solution) during the dilution process.

The fluctuating of adsorption curve was due to the disturbance during shaking process. The orbital shaker was stopped to load & unload of other adsorption bottles (B.O.D bottle). This action had retarded the adsorption of zinc and caused the improper readings.

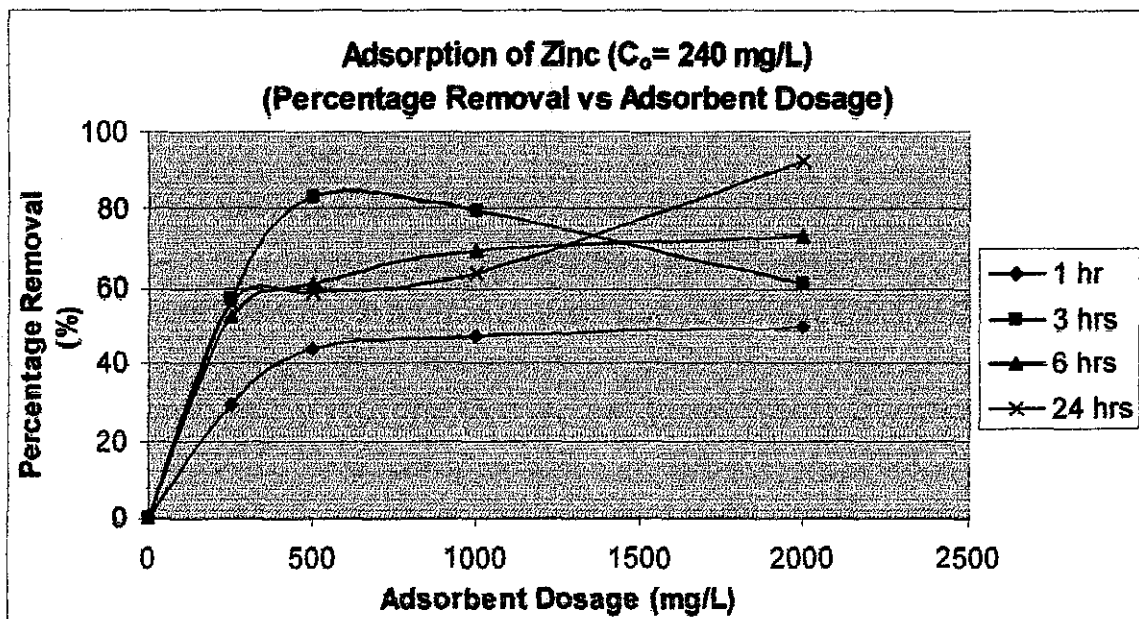


Figure 3 Graph Percentage Removal vs. Adsorbent Dosage ( $C_0 = 240$  mg/L)

The graph shown is to indicate the effect of adsorbent dosage to the percentage of removal by classifying them to the period of adsorption. Generally, was constant after 25 mg dosage and after 100 mg of adsorbent dosage, 3-hour curve decreased from 80% to 61%. Meanwhile, for the 24-hour curve, the percentage increased from 64% to 93%. Other curves experienced less significant increment.

Table 1 Percentage Removal Based on Adsorption Period ( $C_o = 240$  mg/L)

Adsorption Period (hr)	Percentage Removal (%)
1	50
3	61
6	73
24	93

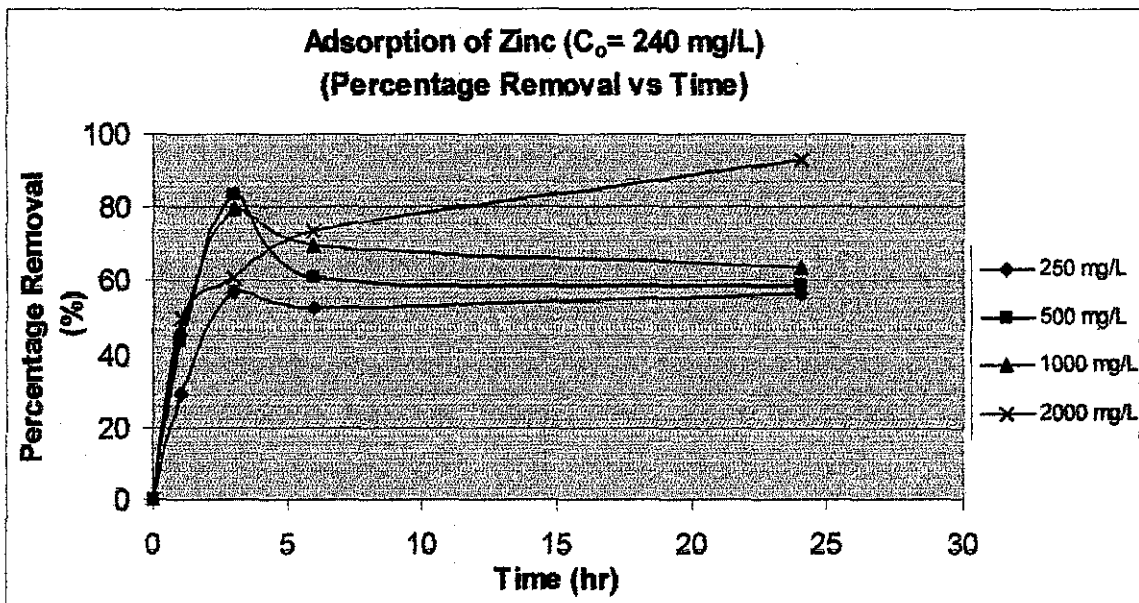


Figure 4 Graph Percentage Removal vs. Time ( $C_o = 240$  mg/L)

The graph above indicates the effect of time to the percentage removal. The highest percentage removal was 93% at 24 hours with the adsorbent dosage of 200 mg. The lowest percentage removal was 29% at 1 hour of adsorption with 25 mg of adsorbent dosage. Generally, the percentages removal were decreased after 3 hours except for 200 mg curve. Table below simplify the percentage removal based on its adsorbent dosage.

Table 2 Percentage Removal based on Adsorbent Dosage ( $C_0 = 240$  mg/L)

Adsorbent Dosage (mg)	Percentage Removal (%)
250	56
500	58
1000	64
2000	93

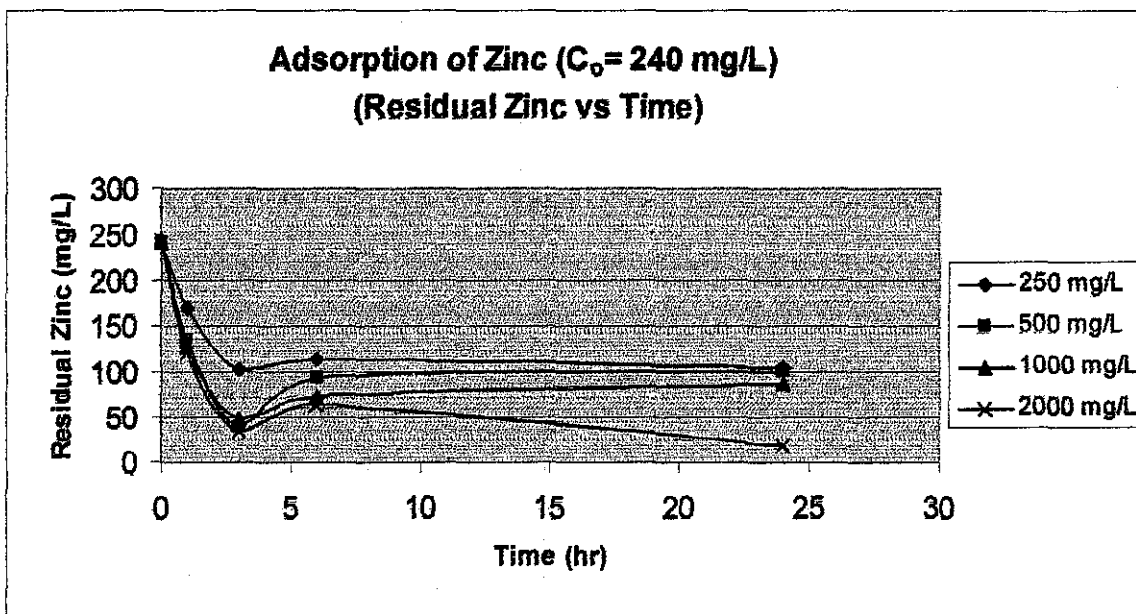


Figure 5 Graph Residual Zinc vs. Time ( $C_0 = 240$  mg/L)

Based on the figure above, there was a trend where after 3-hour of adsorption, the residual zinc would tend to increase. It was very clear when all four adsorbent dosage curves (25, 50, 100 and 200 mg) were increased to 114.5 mg/L, 94 mg/L, 73.5 mg/L, and 63.67 mg/L respectively. Only 200 mg adsorbent dosage was decreased to 18 mg/L of

residual zinc after increment at 6-hour of adsorption. The supposed curve trend should be drastically decreased within 3 to 6 hour of adsorption and consistent throughout until 24 hours. The data in the graph above was tabulated from the graph of Residual Zinc vs. Adsorbent Dosage. Hence, it can be conclude that the factors contributed to the nonconformance were the same.

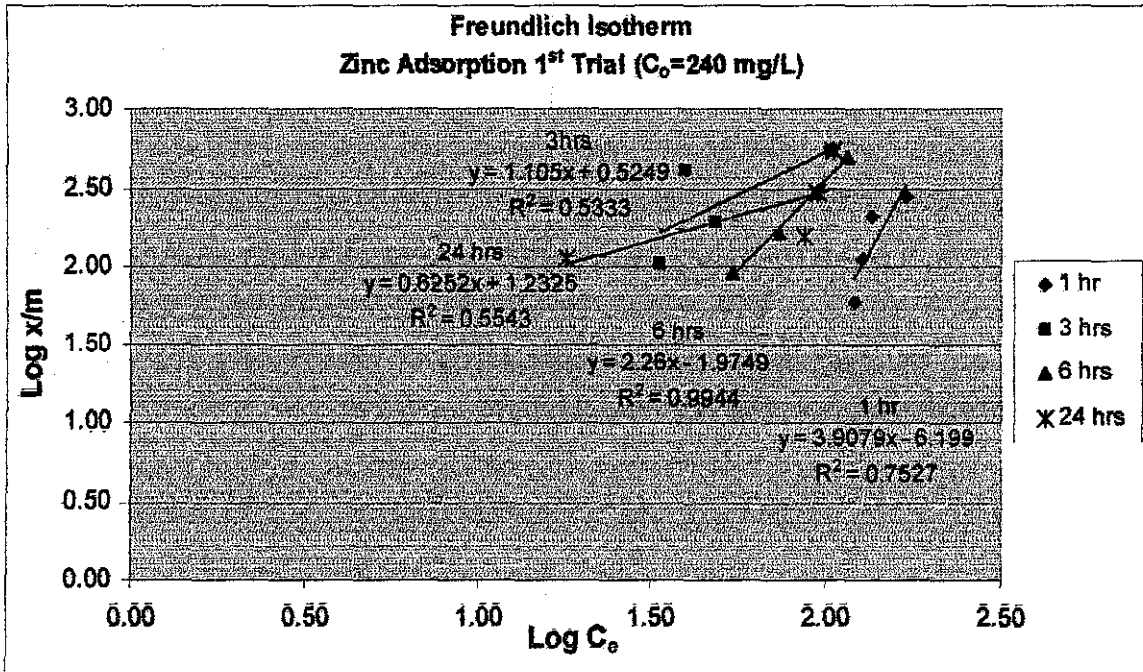


Figure 6 Freundlich Model of Zinc Adsorption C<sub>0</sub>= 240 mg/L

Based on above Freundlich model, 1 and 6-hour lines were considered as the best fit lines. R<sup>2</sup> values for both lines were 0.7527 and 0.9944. During zinc adsorption, 1 and 6-hour adsorption showed the smooth trend curve. This would influence a good fit in Freundlich. 3 and 24-hour line were not so good due to the fluctuation during zinc adsorption (refer Figure 1).

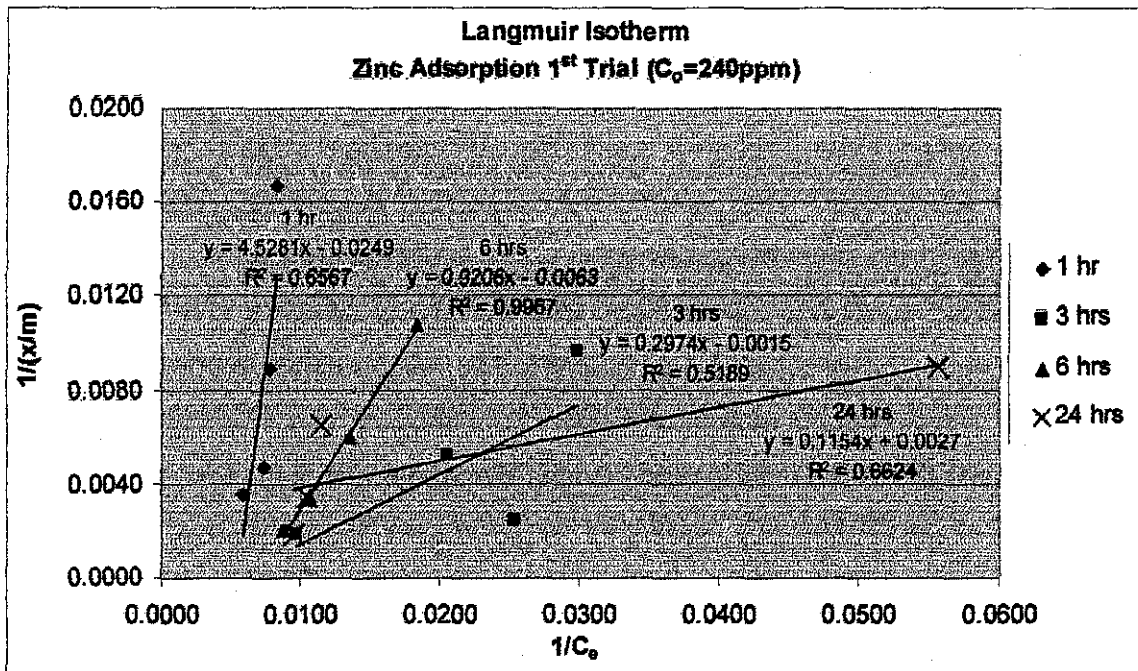


Figure 7 Langmuir Model of Zinc Adsorption  $C_o= 240 \text{ mg/L}$

Figure above shows Langmuir model for zinc adsorption with initial concentration,  $C_o= 240 \text{ mg/L}$ . Same result as Freundlich was expected in Langmuir model. 1 and 6-hour lines were considered as best fitted lines.

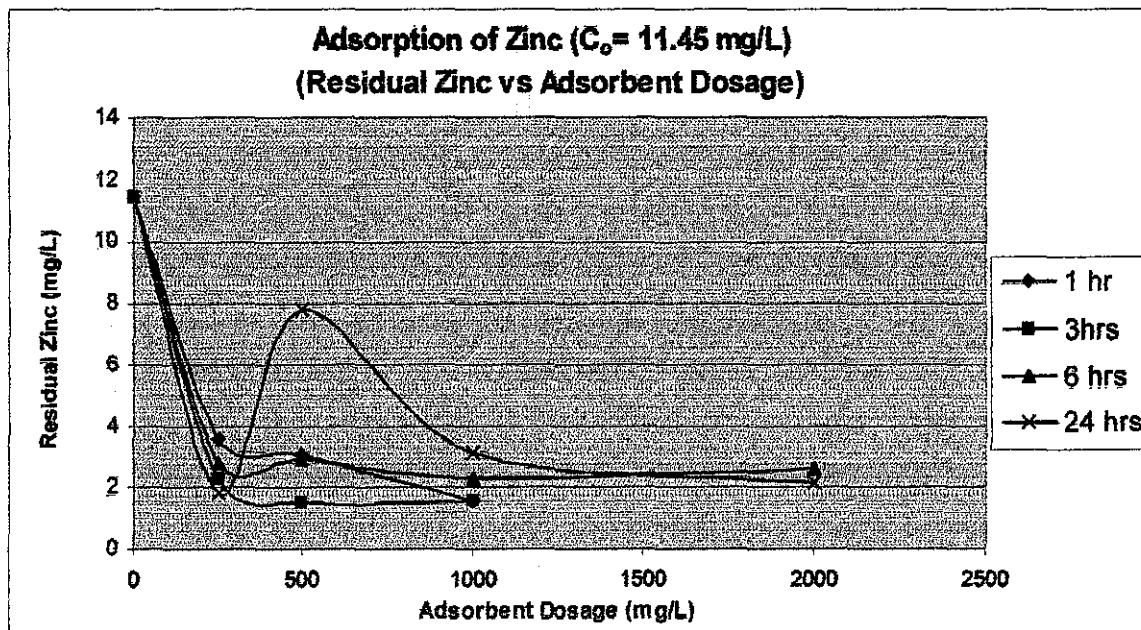


Figure 8 Graph Residual Zinc vs. Adsorbent Dosage ( $C_o= 11.45 \text{ mg/L}$ )

Based on Figure 7, the 1-hour adsorption was only until 100 mg of adsorbent dosage. The reading at 100 mg adsorbent dosage was 1.55 mg/L. The readings for 3-hour adsorption were also until 100 mg of adsorbent dosage. The final reading at 100 mg adsorbent dosage was same as 1-hour period of adsorption which was 1.55 mg/L. The lowest reading at 6-hour curve was 2.3 mg/L of residual zinc at 100 mg of adsorbent dosage. The reading was increased to 2.6 mg/L of adsorbent dosage at 200 mg of adsorbent dosage. At 24-hour of adsorption, the curve was fluctuated and unstable. At 25 mg of adsorbent, the curve experienced decrement until 1.8 mg/L and it was the lowest reading. The reading was drastically changed at 50 mg of adsorbent when the residual zinc was increased until 7.83 mg/L.

Some of the readings were not consistent due to the errors done during the experiment. The major errors were done during the zinc content test. The dilution process was held with improper procedure. There were no transitions of concentration during the dilution process. As in this experiment, the dilution process took place from 1000 mg/L (stock solution) directly to 10 mg/L and 1 mg/L. Hence, the desired initial concentration  $C_0$  was hard to be obtained. The actual  $C_0$  might be less or exceed the desired  $C_0$ .

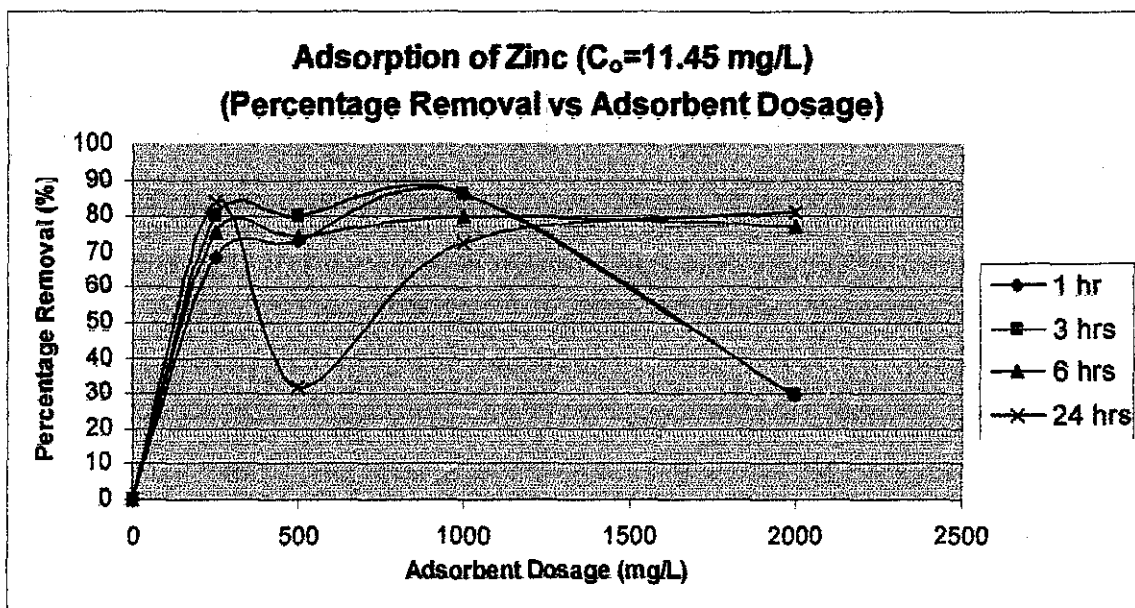
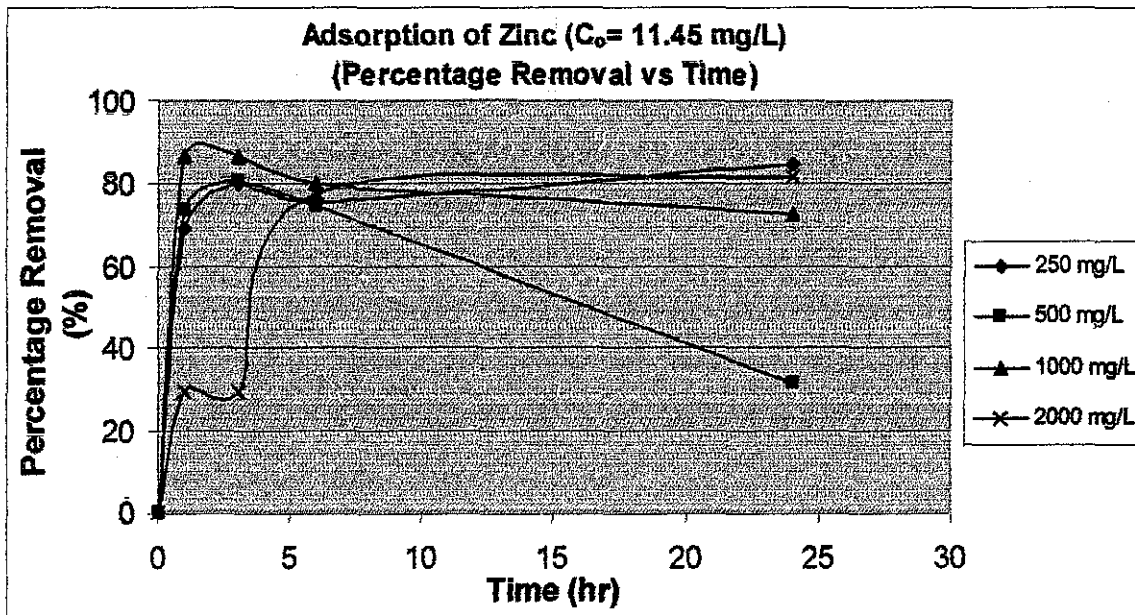


Figure 9 Graph Percentage Removal vs. Adsorbent Dosage ( $C_0 = 11.45$  mg/L)

The graphs in Figure 9 indicate the percentage removal for every adsorbent dosage. There were several significant drops of percentage removal which were 32% at 50 mg of adsorbent dosage for 24-hour curve and 30% at 200 mg of adsorbent dosage for 1 and 3-hour curve. The percentage of removal was based on the graph of Residual Zinc vs. Adsorbent Dosage. Table below shows percentage removal for every adsorption period.

**Table 3 Percentage Removal Based on Adsorption Period ( $C_0 = 11.45$  mg/L)**

Adsorption Period (hr)	Percentage Removal (%)
1	30
3	30
6	77
24	81



**Figure 10 Graph Percentage Removal vs. Time ( $C_0 = 11.45$  mg/L)**

Based on Figure 10, it shows the effect of time to the percentage removal of zinc. The highest percentage removal was at 1 hour of adsorption with the percentage of 86% and

the adsorbent dosage was 100 mg. The lowest percentage was at 1 and 3-hour of adsorption with the percentage of 30%. The adsorbent dosage used was 200 mg. In 50 mg curve, after 6 hours the percentage of removal was dropped from 74% until 32%. In 100 mg curve, the highest percentage removal was at 1 and 3 hours. The percentage removal was 86%. After 3 hours, the percentage removal was dropped until 72% at 24 hours. Table 4 shows percentage removal for every adsorbent dosage

Table 4 Percentage Removal based on Adsorbent Dosage ( $C_o = 11.45 \text{ mg/L}$ )

Adsorbent Dosage (mg)	Percentage Removal (%)
250	56
500	59
1000	64
2000	93

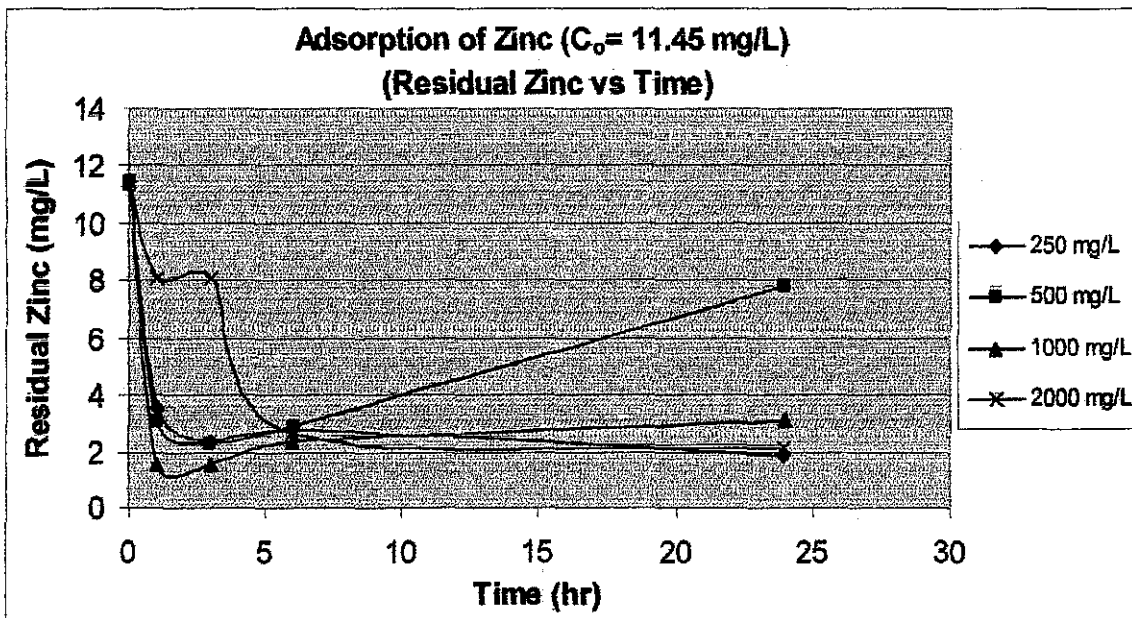


Figure 11 Graph Residual Zinc vs. Time ( $C_o = 240 \text{ mg/L}$ )



The graph above indicates the effect of time in the zinc adsorption. The effect of time can be seen within 3 to 6 hours. The adsorption rate is higher at that period of time because the residual zinc was dropped drastically. The lowest reading was at 3 hour which was 1.55 mg/L with the adsorbent dosage of 100 mg. In 200 mg adsorbent dosage, the curve behaved a bit different. The amount of residual zinc increased after 1 hour and the reading at 3 hour was 8.07 mg/L. The reading at 6 hours was 2.6 mg/L and it was constantly decreased until 2.15 mg/L after 24 hours. Reading at 24 hours for 50 mg adsorbent dosage was highest among others which was 7.83 mg/L.

All the inconsistencies of the readings might be contributed by the way of the experiment were done. During zinc content tests, the apparatus used (e.g. beaker, measuring cylinder, pipette, etc.) might not be washed properly by using special detergent for apparatus. Hence, some of the residual zinc from previous tests might stick on the apparatus that contributed to the inconsistencies of the readings.

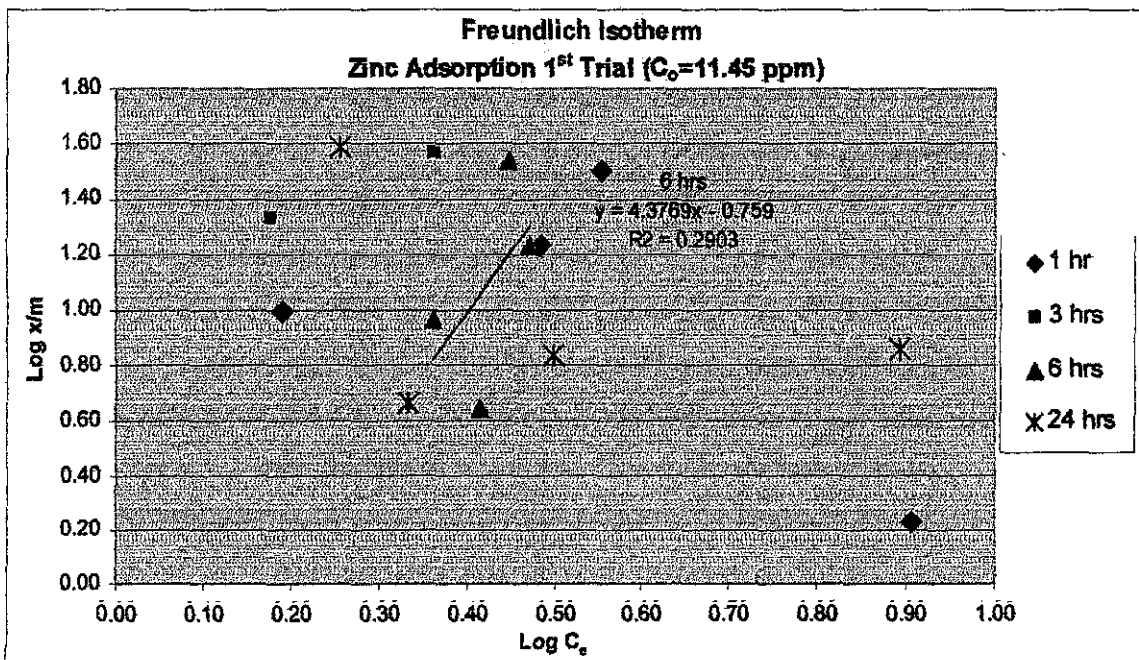


Figure 12 Freundlich Model of Zinc Adsorption ( $C_0 = 11.45$  mg/L)

The above figure shows Freundlich isotherm for zinc adsorption with  $C_0 = 11.45$  mg/L. Only 6-hour followed the trend of Freundlich isotherm. The other 1, 3, and 24-hour line

were not following the trend. The slopes for all the lines were negative. However, the 6-hour line was not a good fitted line with  $R^2 = 0.2903$ .

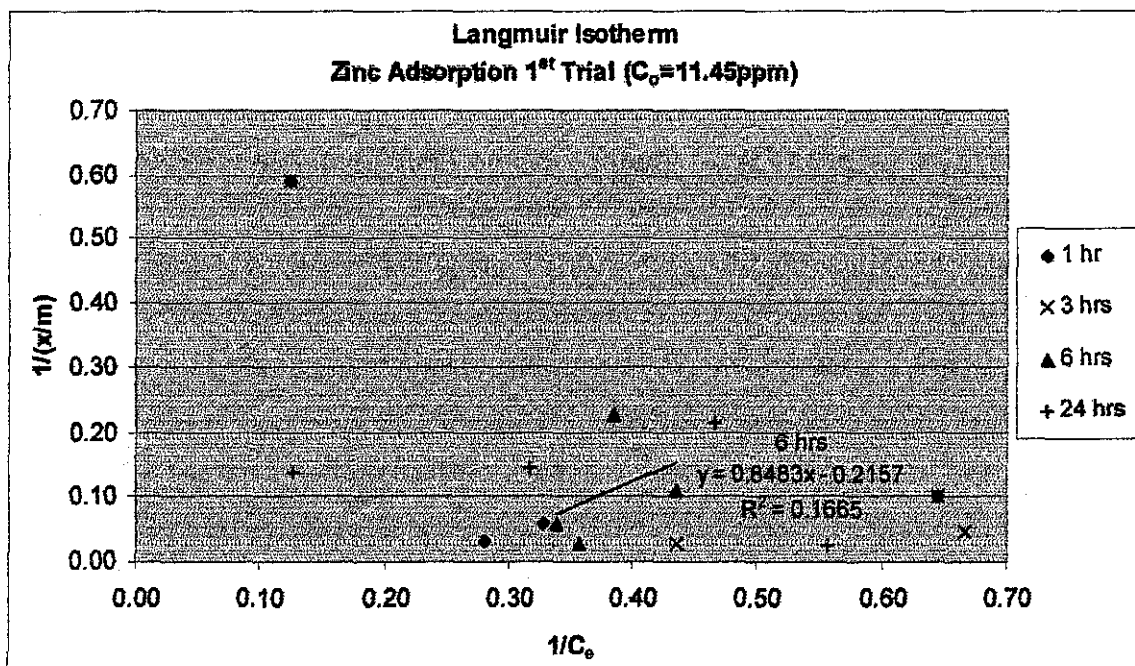


Figure 13 Langmuir Model of Zinc Adsorption C<sub>0</sub>= 11.45 mg/L

Figure 12 shows Langmuir isotherm for zinc adsorption C<sub>0</sub>= 11.45 mg/L. Only 6-hour followed the trend for Langmuir isotherm. The other three adsorption periods gave negative results. All the slopes were negative. It can be said that the zinc adsorption for C<sub>0</sub>= 11.45 mg/L was not work.

#### 4.1.2 Second Trial

The difference between first and second trial is the adsorbent dosages applied. In the second trial the dosages used were 25, 50, 75 and 100 mg for every 100 mL of aqueous zinc solution. The shaking time (t) was same as the first trial.

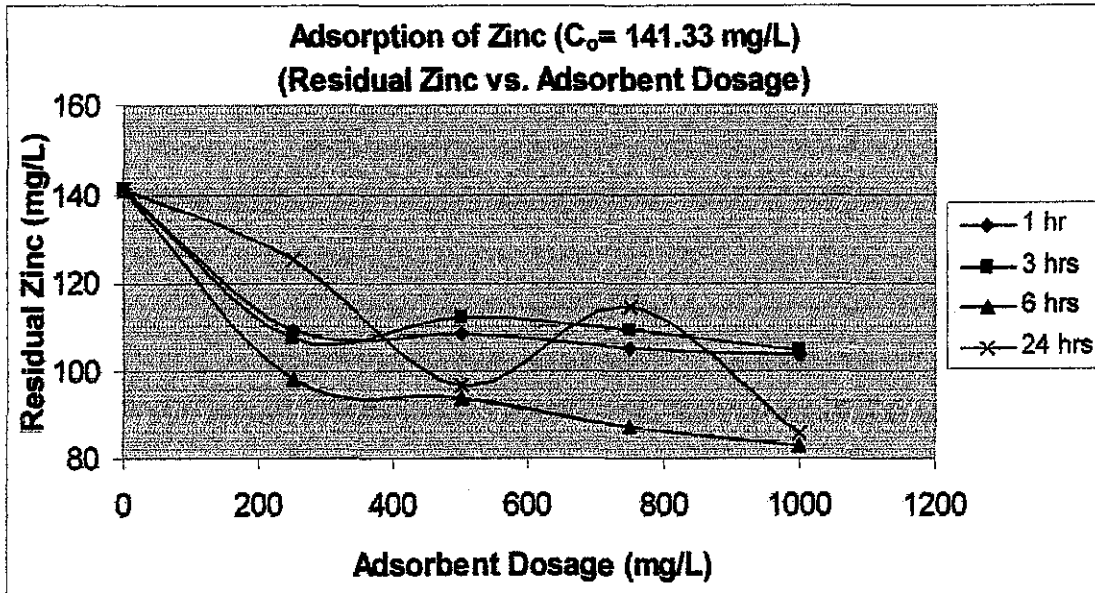


Figure 14: Graph Residual Zinc vs. Adsorbent Dosage ( $C_0 = 141.33$  mg/L)

Based on figure 13, the initial concentration was 141.33 mg/L. All the adsorption shows normal trend. However, 24-hour curve fluctuated at 750 mg/L of adsorbent dosage. It was increased from 96.33 to 114.5 mg/L and it was decreased to 85.5 mg/L at dosage of 1000mg/L. The lowest residual zinc was 83 mg/L at 24 hours of adsorption. The highest residual zinc was 104.3 mg/L after 3 hour of adsorption.

Fluctuation of reading happened due to several factors. The most likely factor was error of dilution during measurement of zinc.

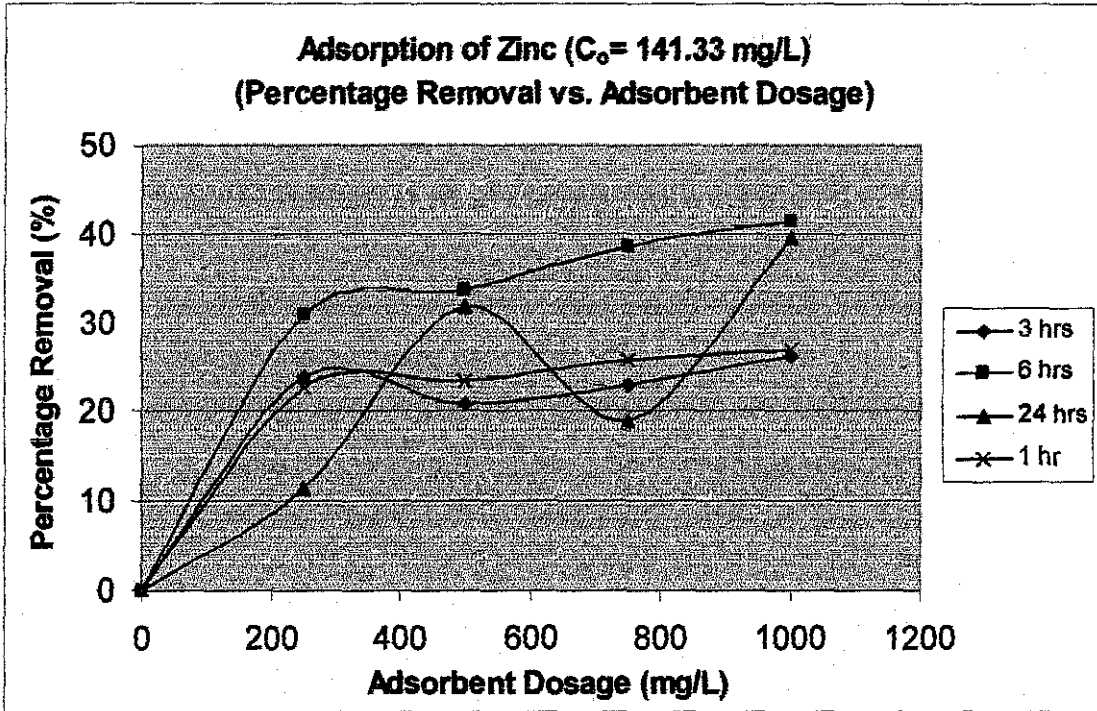


Figure 15: Graph Residual Zinc vs. Time (2<sup>nd</sup> Trial)

Based on the graph above, the optimum adsorption time was at 6-hour. The residual zinc for 75 mg and 25 mg curve were the highest, 125 mg/L and 114.5 mg/L respectively. All the curves were fluctuated. The curves were fluctuated at 3 hours and 24 hours. The expected curve should decrease as the contact time increase. The lowest residual zinc obtained was 83 mg/L with 6-hour adsorption period.

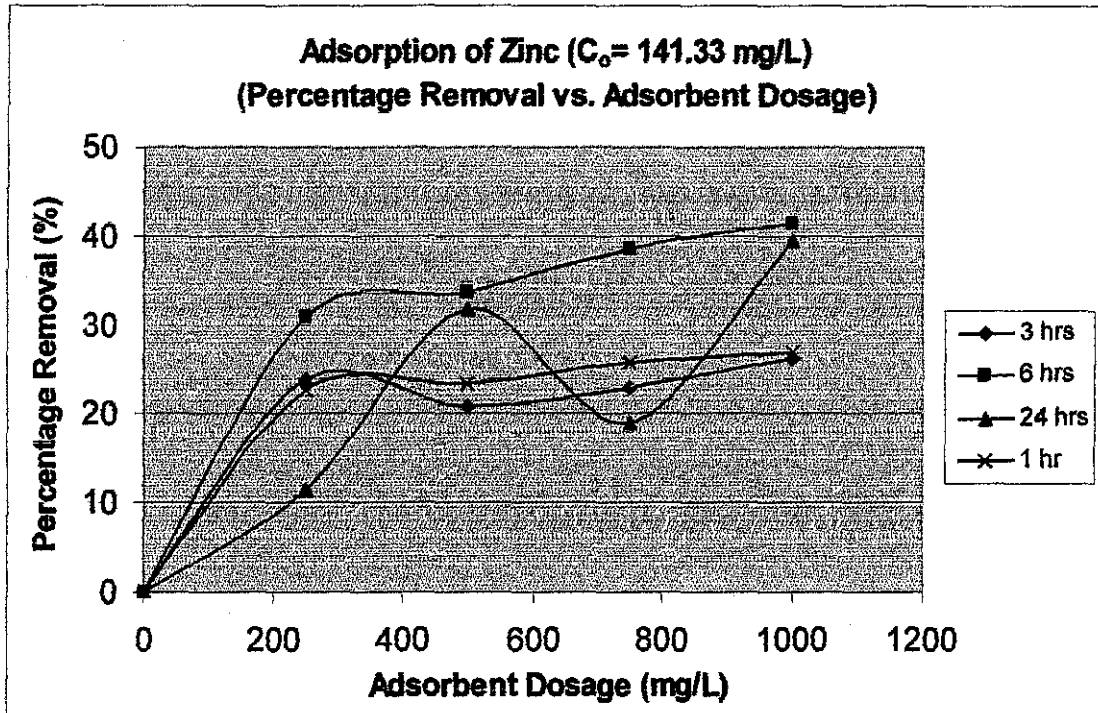


Figure 16: Percentage Removal vs. Adsorbent Dosage ( $C_o = 141.33$  mg/L)

Based on the figure above, the highest percentage removal was 41% at 6 hours of adsorption. The lowest percentage removal was 26% at 3 hours of adsorption.

Percentage removal at 24-hour adsorption was fluctuated from 31.84 to 19% at 500 and 750 mg/L of adsorbent dosage respectively. Table below shows percentage removal based on adsorption period.

Table 5 Percentage Removal Based on Adsorption Period ( $C_o = 141.33$  mg/L)

Adsorption Period (hr)	Percentage Removal (%)
1	27
3	26
6	41
24	40

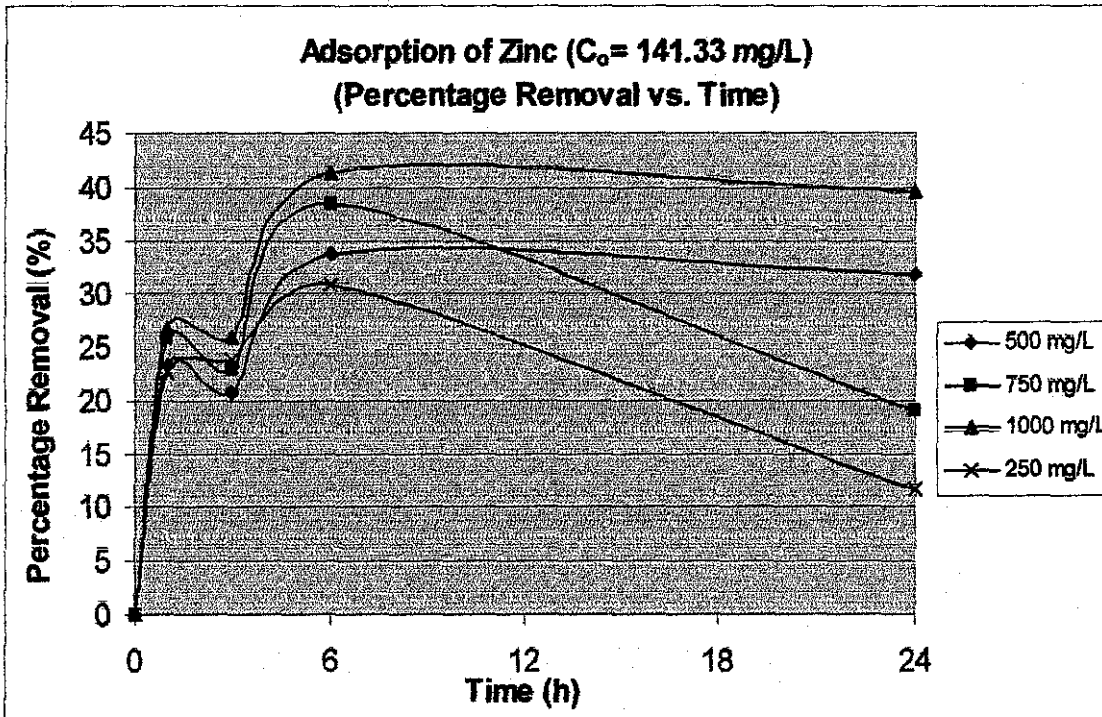


Figure 17: Graph Percentage Removal vs. Time ( $C_o = 141.33$  mg/L)

Based on Figure 12, the highest percentage removal was at 6 hours with adsorbent dosage of 1000 mg/L. The lowest percentage removal was 12% with adsorbent dosage of 250 mg/L. The table below summarizes the percentage removal based on adsorption period. The figure indicates that all the highest percentages removal were at 6-hour of adsorption.

Table 6 Percentage Removal based on Adsorbent Dosage ( $C_o = 141.33$  mg/L)

Adsorbent Dosage (mg/L)	Percentage Removal (%)
250	31
500	34
750	38
1000	41

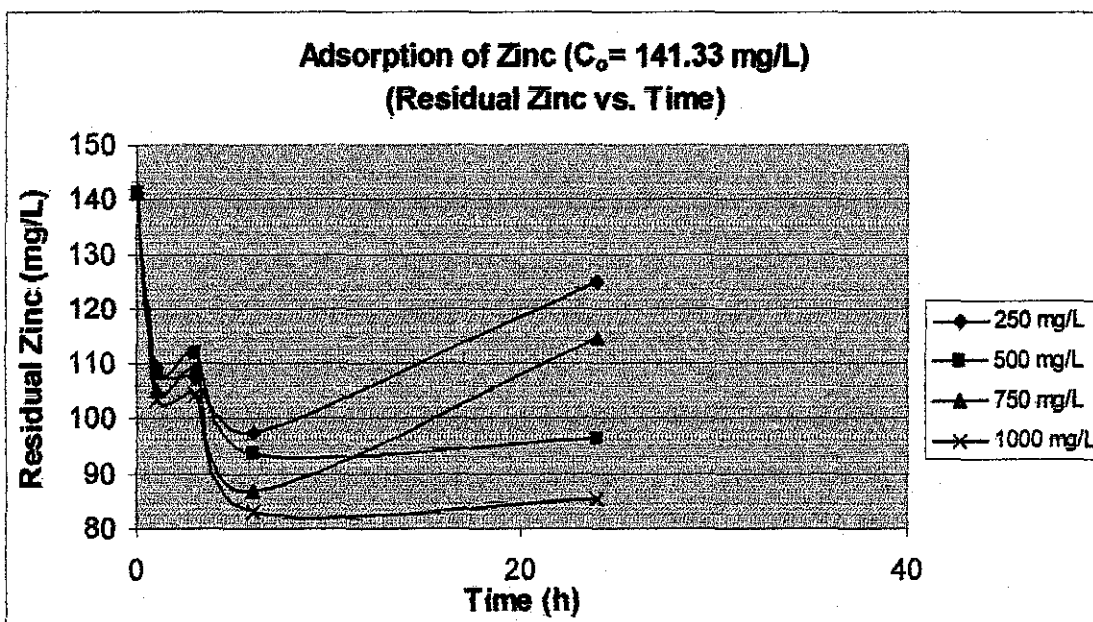
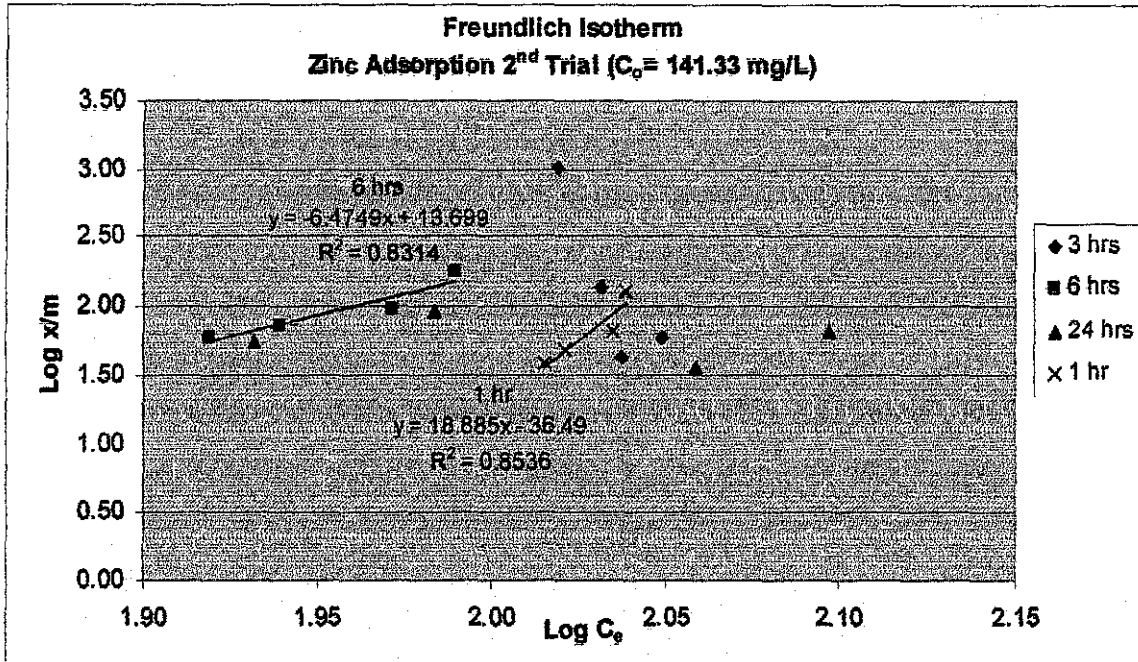


Figure 18 Graph Residual Zinc vs. Time ( $C_o = 141.33$  mg/L)

The figure above shows residual zinc over time. Based on the graph trend, the lowest residual zinc obtained at 6 hours of adsorption. The lowest residual zinc was 83 mg/L at adsorbent dosage of 1000 mg/L. The residual zinc readings were increased after 6 hours. The inconsistencies were due to the errors during the experiment. During zinc content tests, the apparatus used (e.g. beaker, measuring cylinder, pipette, etc.) might not be washed properly by using special detergent for apparatus. Hence, some of the residual zinc from previous tests might stick on the apparatus that contributed to the inconsistencies of the readings.



**Figure 19 Freundlich Model of Zinc Adsorption (C<sub>0</sub> = 141.33 mg/L)**

Based on the figure 18, only 1 and 6-hour shows good fitted lines. The other 3 and 24-hour lines were not following normal trend. The slopes were negative. K<sub>f</sub> values for 1 and 6-hour were 2.81x10<sup>-37</sup> and 5.27x10<sup>14</sup> respectively. Hence, 6-hour adsorption possessed the higher adsorption capacity if were compared to 1-hour.

The negative slope happened due to the inconsistencies during the adsorption process. Other than that, the Freundlich isotherm was proved by using mathematical analysis. Thus, the performance of adsorbent could be varied in real condition.



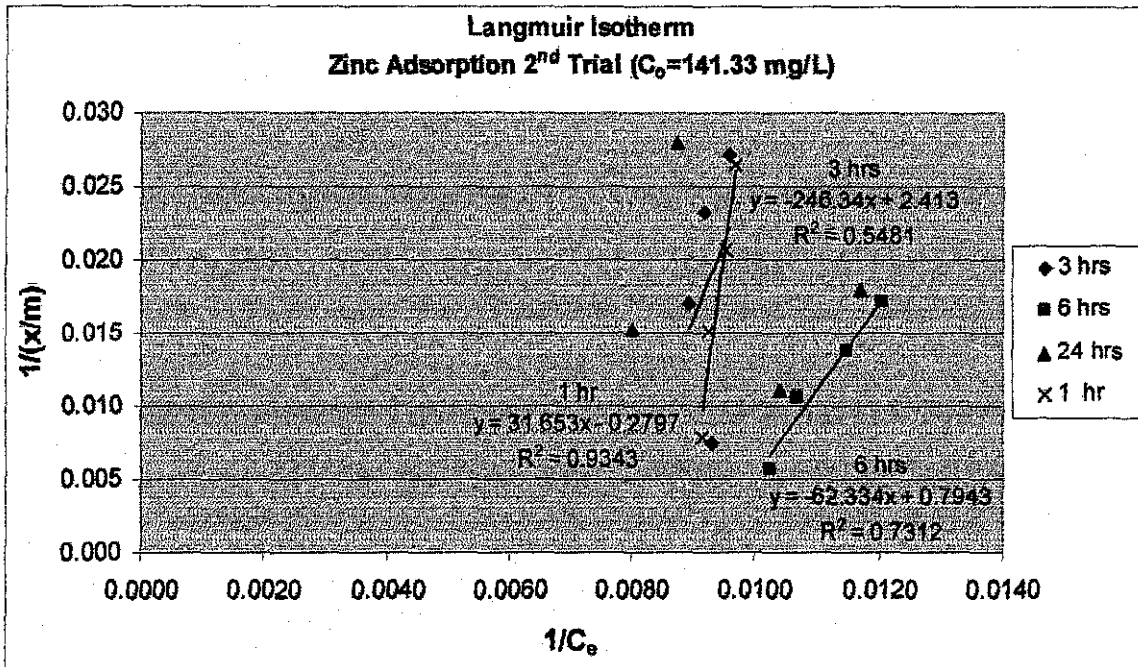


Figure 20 Langmuir Isotherm for Zinc Adsorption ( $C_0= 141.33$  mg/L)

Figure above shows Langmuir isotherm for zinc adsorption  $C_0= 141.33$  mg/L. There were three fitted lines that suit to the normal trend which were 1, 3, and 6-hour. However, in Freundlich isotherm, 6-hour was justified as the higher adsorption capacity compared to 1-hour adsorption.

There was inconsistency for 3-hour adsorption. Its slope was negative in Freundlich isotherm However positive in Langmuir isotherm. Further study is needed in order to justify this situation.

## 4.2 PHASE 2

During phase 2, two trials were conducted. The 1<sup>st</sup> trial was done in two initial concentrations which were 10 mg/L and 110 mg/L. The adsorbent dosages used were 25, 50, 100, and 200 mg.

In the 2<sup>nd</sup> trial, experiment of adsorption of zinc with initial concentration of 10 mg/L was done. However, the adsorbent dosages were changed to 1000, 2000, 3000, and 4000 mg/L.

### 4.2.1 First Trial

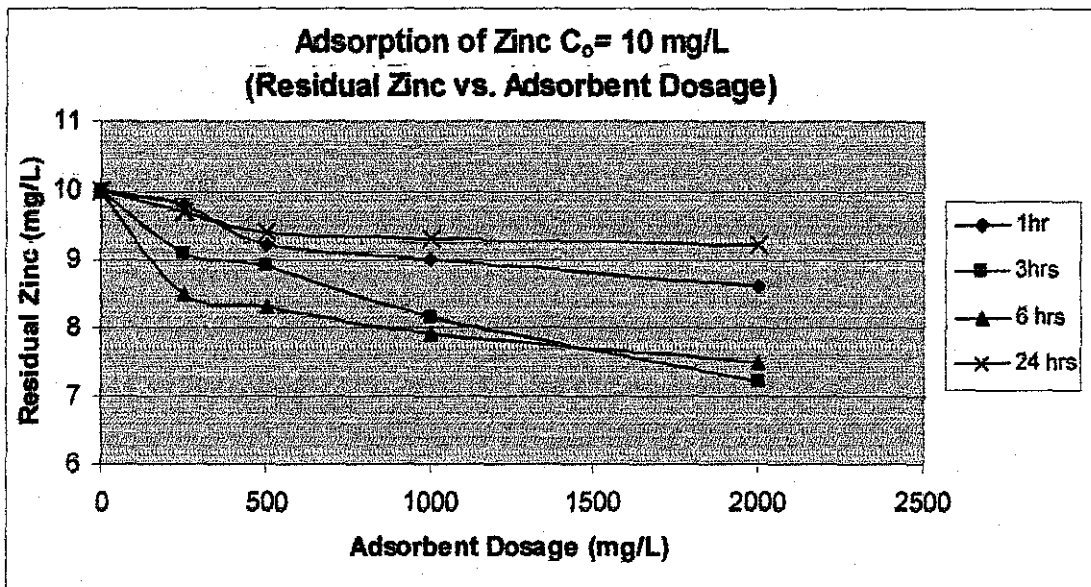


Figure 21 Graph Residual Zinc vs. Adsorbent Dosage ( $C_0 = 10$  mg/L)

The graph above shows the relationship of residual zinc over time. The initial concentration of zinc was 10 mg/L. The lowest residual zinc was 7.2 mg/L with adsorbent of 2000mg/L at 3 hours. 24-hour curve shows a weird trend where it held the

highest value of residual zinc if were compared to others. The other two residuals zinc were 8.6mg/L at 1 hour and 7.5mg/L at 6 hours.

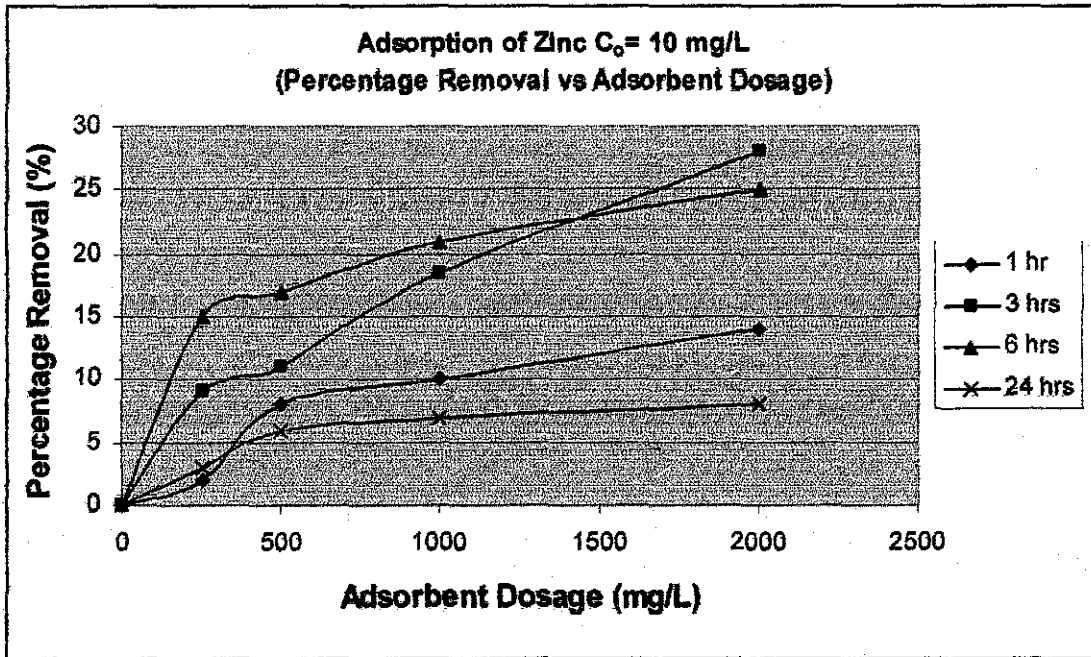


Figure 22 Graph Percentage Removal vs. Adsorbent Dosage ( $C_0 = 10$  mg/L)

Figure 21 indicates the percentage removal over the adsorbent dosage. The highest percentage removal was 28% at 3 hrs of adsorption with adsorbent dosage of 2000 mg/L. The lowest percentage of removal was 8% at 24 hours of adsorption with the same adsorbent dosage of 2000 mg/L. Table below summarizes the percentage removal based on its adsorption period.

Table 7 Percentage Removal based on Adsorption Period ( $C_0 = 10$  mg/L)

Adsorption Period (hr)	Percentage Removal (%)
1	14
3	28
6	25
24	8

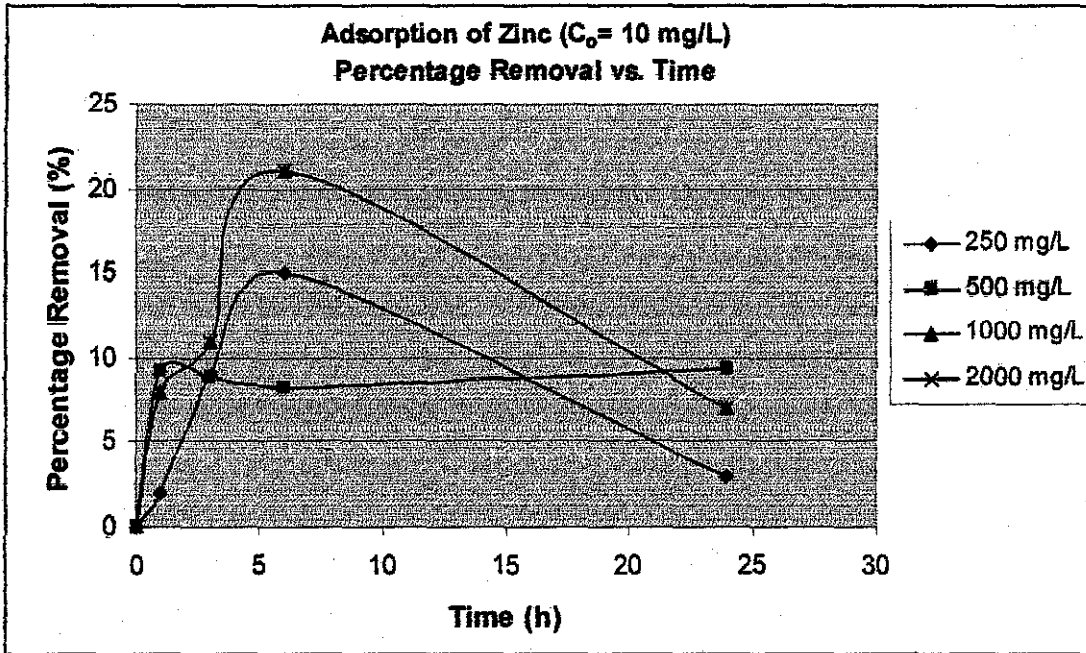


Figure 23 Graph Percentage Removal vs. Time ( $C_0 = 10$  mg/L)

The graph above shows percentage removal vs. time. The highest percentage removal was 21% at 6 hours of adsorption with adsorbent dosage of 1000 and 2000 mg/L. The lowest percentage removal after the 24 hours of adsorption was 3% at 250 mg/L of adsorbent dosage. Percentages removal at 6-hour were the highest if were compared to other adsorption period. The table below shows the percentage removal based time.

Table 8 Percentage Removal of Zinc based on Adsorbent Dosage ( $C_0 = 10$  mg/L)

Adsorbent Dosage (mg/L)	Percentage Removal (%)
250	15
500	8
1000	21
2000	21

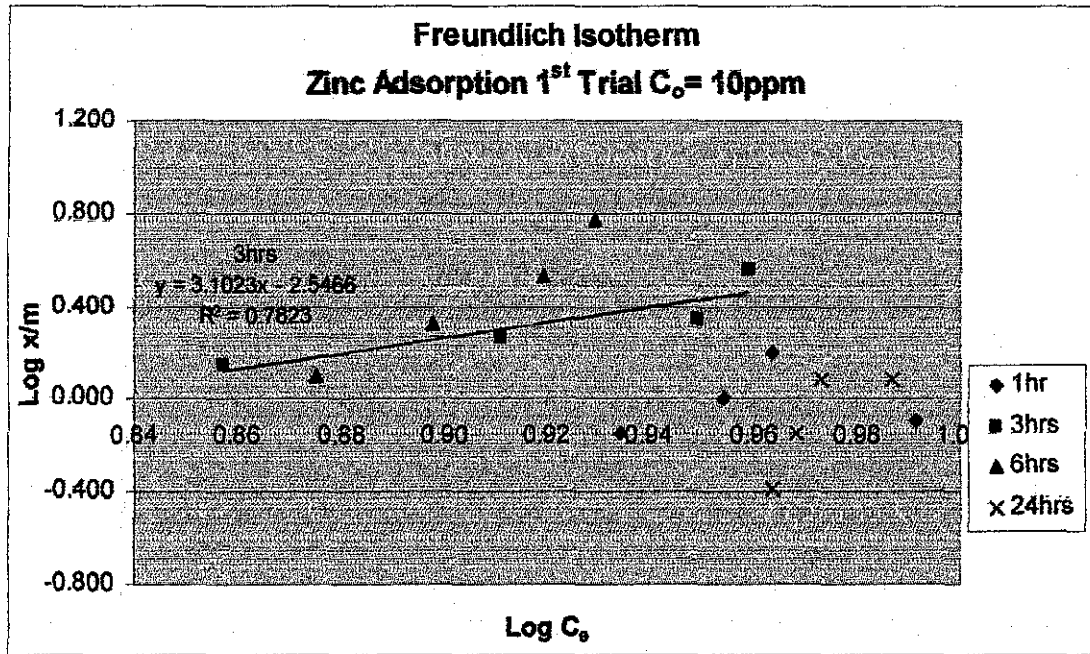


Figure 24 Freundlich Isotherm for Zinc Adsorption ( $C_o = 10\text{ mg/L}$ )

Figure above shows Freundlich isotherm of zinc adsorption model with initial concentration 10 mg/L. Only 3-hour line followed the right trend (refer Figure 20). This is due to consistent readings during the adsorption process.  $K_f$  value for 3-hour was  $2.99 \times 10^{-3}$ .

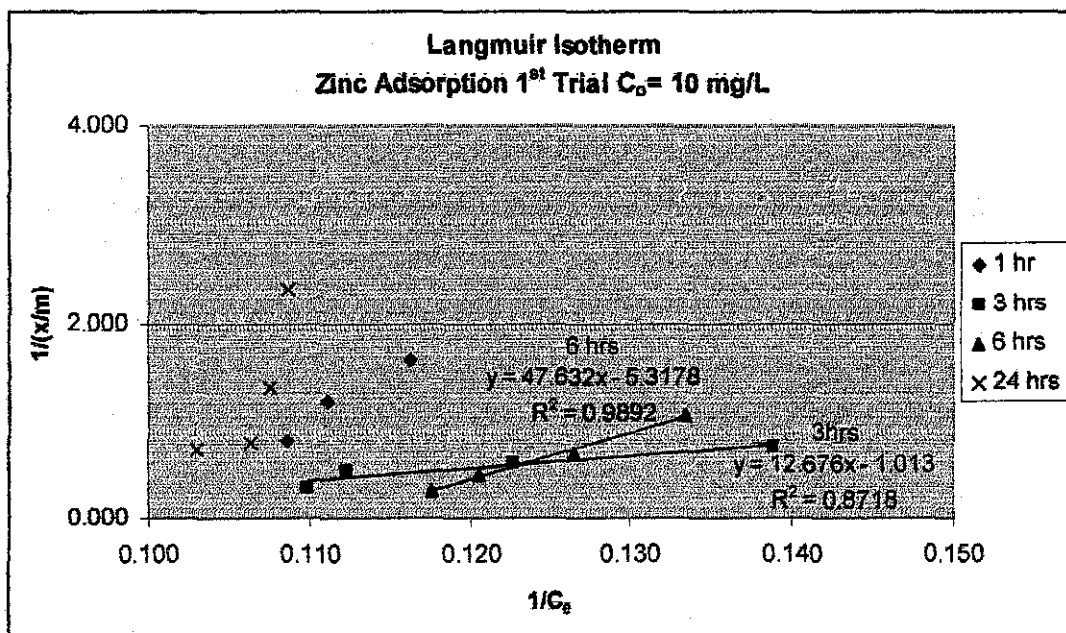


Figure 25 Langmuir Isotherm for Zinc Adsorption ( $C_o = 10\text{ mg/L}$ )

The figure shows Langmuir isotherm for zinc adsorption with initial concentration of 10 mg/L. It was a bit different than previous Freundlich isotherm. 3 and 6-hour line were the best if were compared to rest

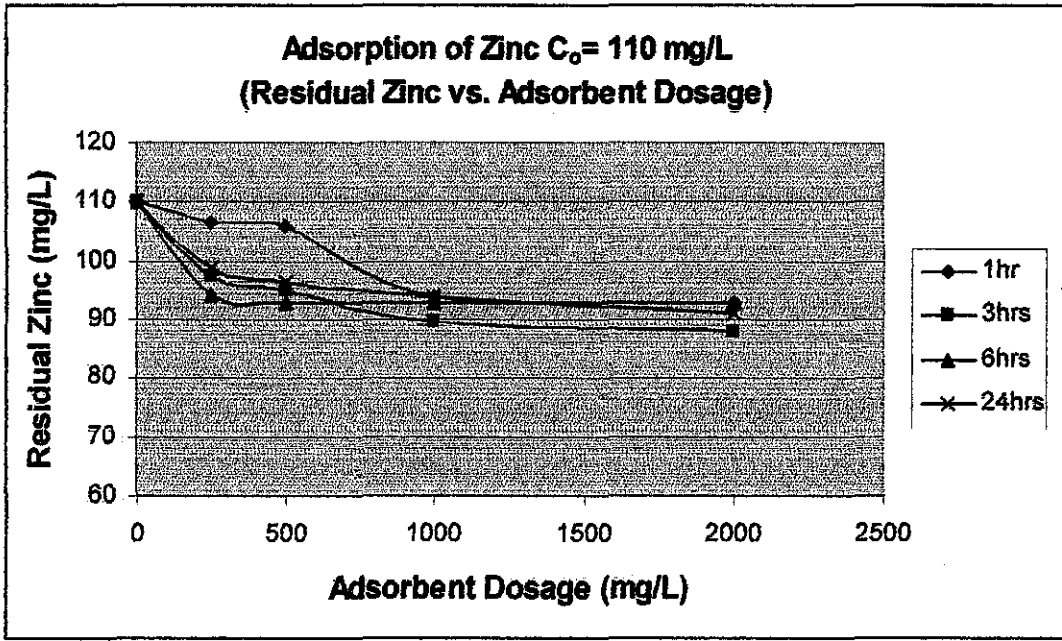


Figure 26 Graph Residual Zinc vs. Adsorbent Dosage  $C_0= 110$  mg/L

Figure above shows graph residual zinc vs. adsorbent dosage with initial concentration of 110 mg/L. The lowest residual zinc obtained was 88 mg/L at 3 hours. 1-hour curve shows a weird trend. The residual zinc experienced a drop from 106 mg/L to 94 mg/L with 500 mg/L and 1000 mg/L of adsorbent dosage respectively. Reading would be constant 6 and 24-hour curve after the supply of 250 mg/L adsorbent dosage. The adsorption curves in this figure were not consistent. It did not match with the theory that the higher the adsorption time, the higher the percentage of adsorption. The 24 hour should have the highest percentage.

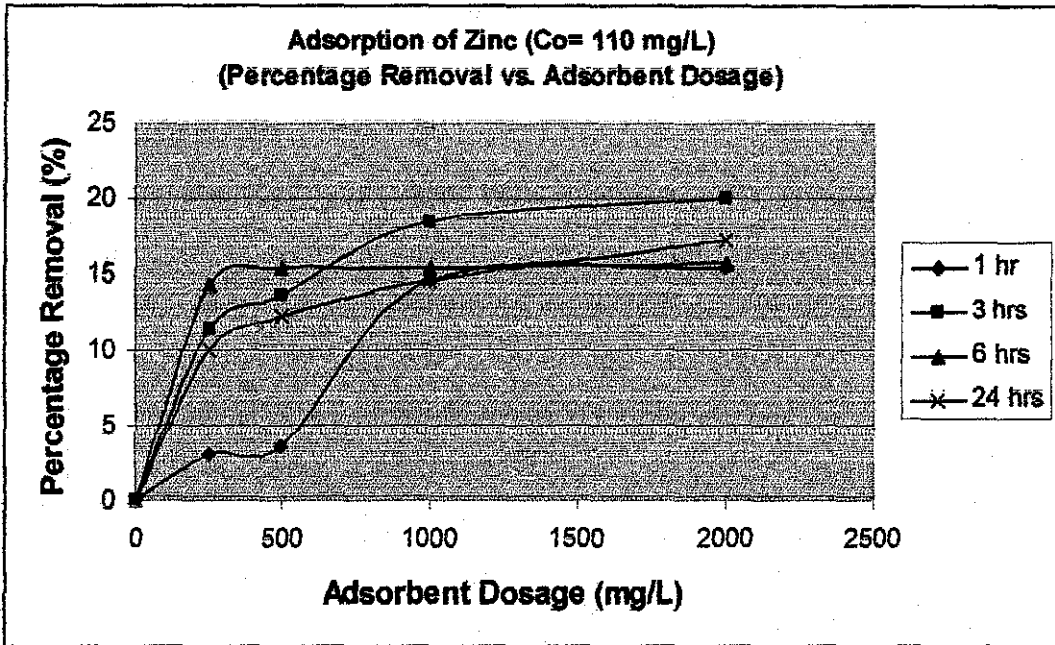


Figure 27 Graph Percentage Removal vs. Adsorbent Dosage ( $C_o = 110$  mg/L)

The highest percentage of zinc adsorption in the figure was 20% at 3 hour. The initial concentration was 110 mg/L and its final concentration was 88 mg/L. The lowest percentage of zinc adsorption was 15.45% at 1 hour. The initial concentration was 110 mg/L and its final concentration was 92.67 mg/L. The second higher of percentage of adsorption was 17.27% at 24 hours. The adsorption curves in this figure were not consistent. It did not match with the theory that the higher the adsorption time, the higher the percentage of adsorption. The 24 hour should have the highest percentage. The inconsistency was also due to the shaking process. Table below indicates percentage removal based on adsorption period.

Table 9 Percentage Removal of Zinc based on Adsorption Period ( $C_o = 110$  mg/L)

Adsorption Period (hr)	Percentage Removal (%)
1	15
3	20
6	16
24	17

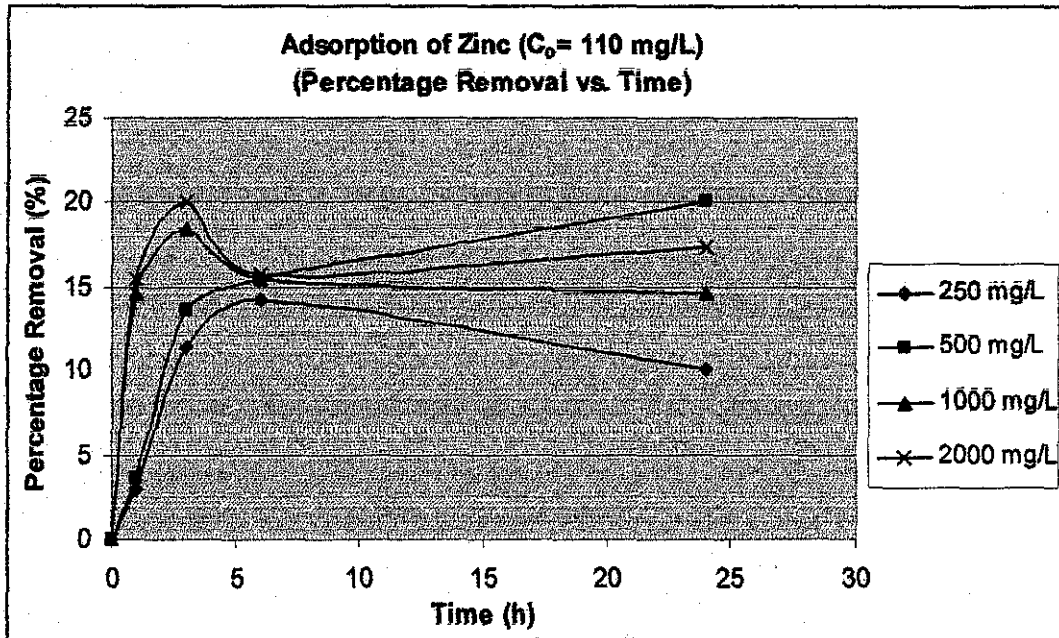


Figure 28 Graph Percentage Removal vs. Time ( $C_0 = 110$  mg/L)

The figure above shows percentage removal over time. The highest percentage was 20% at 3 hours with adsorbent dosage of 2000 mg/L. It can be said that the percentage removal achieved its highest reading at 3 hours of adsorption. The table below shows percentage removal based on adsorbent dosage.

Table 10 Percentage Removal of Zinc based on Adsorbent Dosage ( $C_0 = 110$  mg/L)

Adsorbent Dosage (mg/L)	Percentage Removal (%)
250	15
500	8
1000	21
2000	21



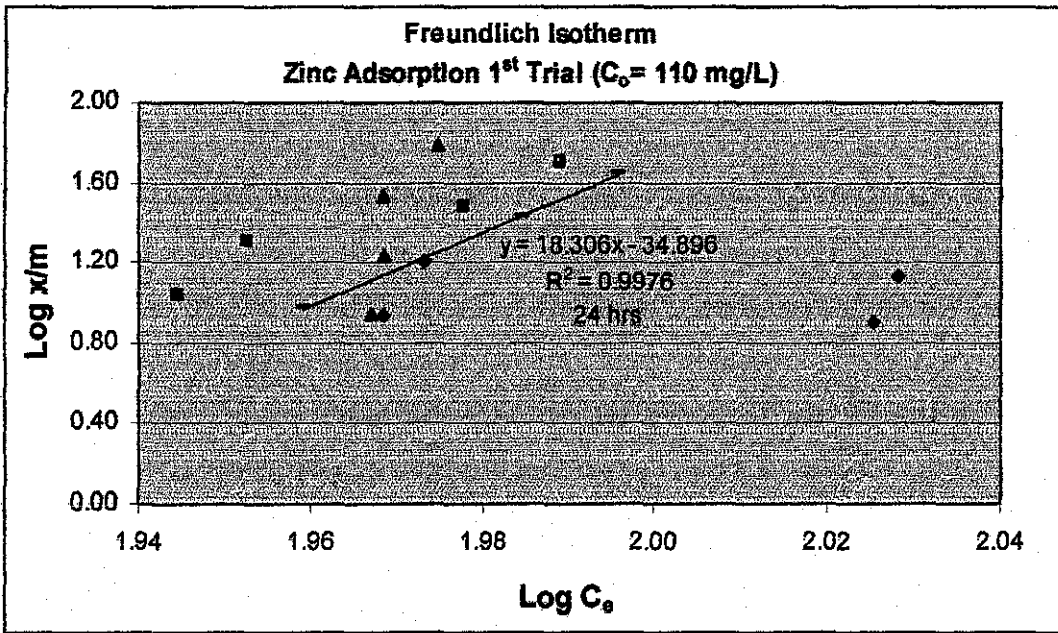
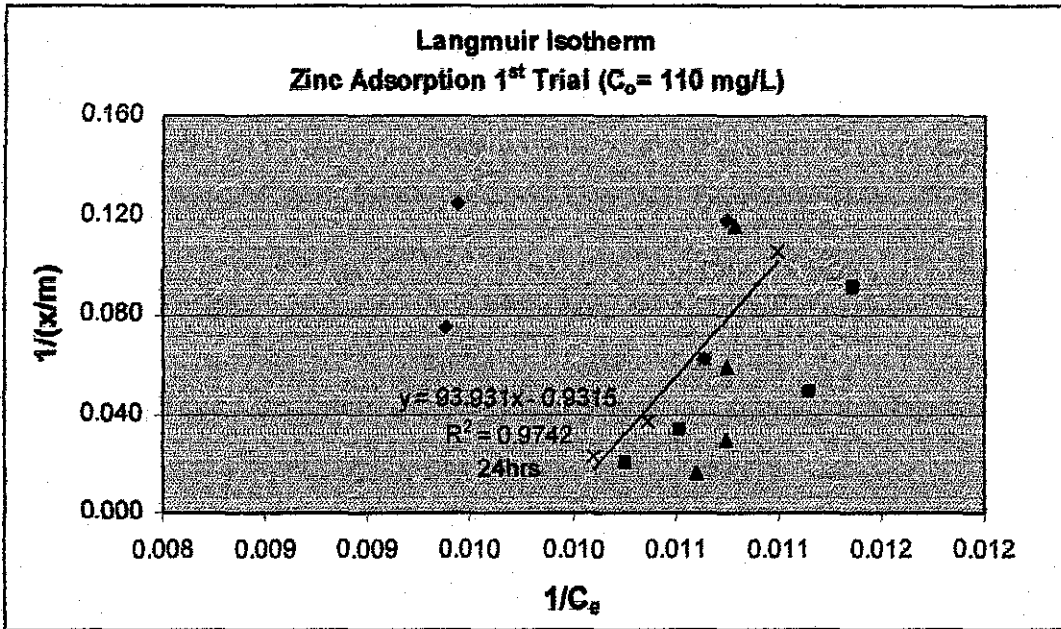


Figure 29 Freundlich Isotherm for Zinc Adsorption (C<sub>0</sub> = 110 mg/L)

Figure above shows Freundlich isotherm for zinc adsorption with initial concentration of 110 mg/L. Only 24-hour line had a good fit if were compared to others. The other adsorption periods were not following the trend for Freundlich isotherm. K<sub>f</sub> value for 24-hour was  $1.26 \times 10^{-35}$ .



**Figure 30 Langmuir Isotherm for Zinc Adsorption (Co= 110 mg/L)**

Figure above shows Langmuir isotherm for zinc adsorption with initial concentration of 110 mg/L. As same as previous Freundlich isotherm, only 24 hour line was a good fitted line with  $R^2$  was 0.9742. The other adsorption period had poor fittings with low  $R^2$  value.

#### 4.2.2 Second Trial

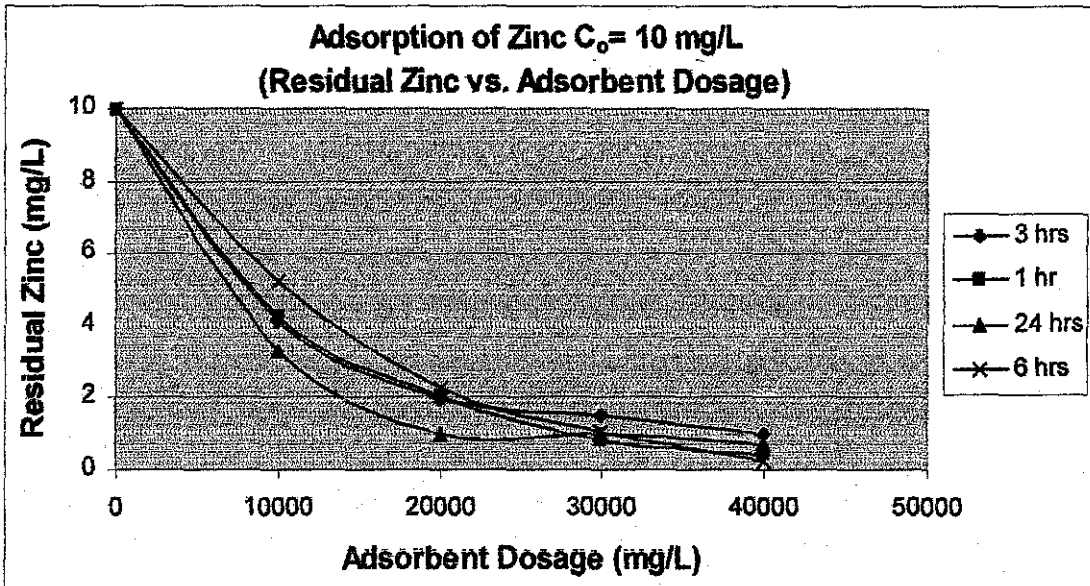


Figure 31 Graph Residual Zinc vs. Adsorbent Dosage ( $C_0 = 10$  mg/L)

The figure above shows adsorption of zinc with initial concentration of 10 mg/L. The lowest residual zinc obtained was 0.25 mg/L. All the final concentrations in this adsorption model were below 1. All of adsorption curves did follow the right trend. The adsorption was active before 20000 mg/L of adsorbent dosage and getting slower and constant after 20000 mg/L of adsorbent dosage

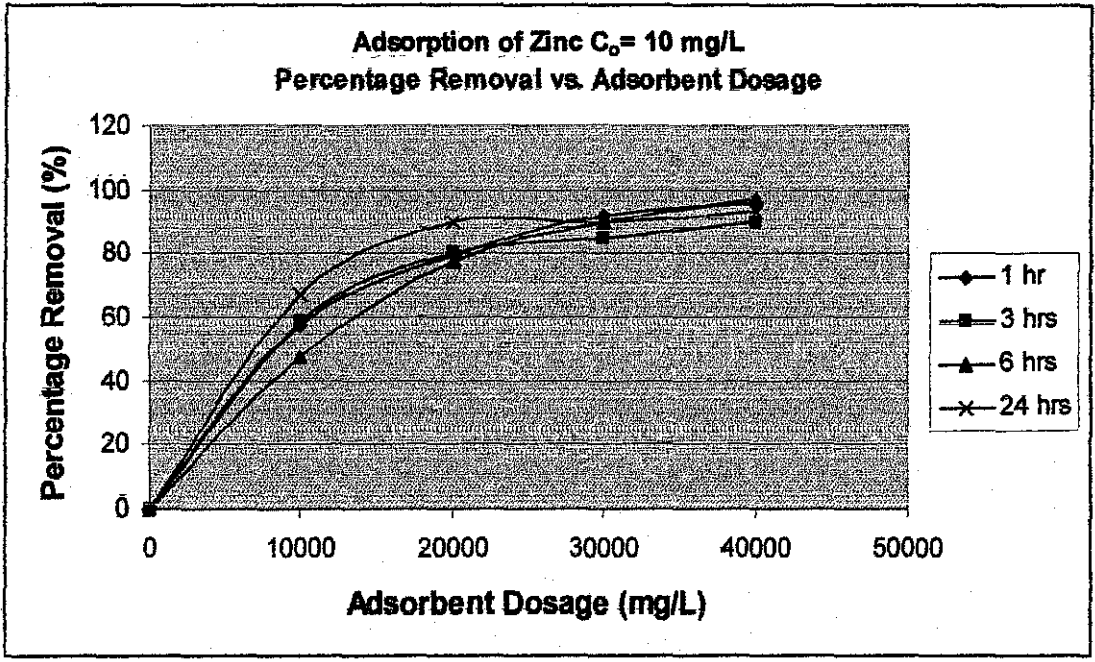


Figure 32 Graph Percentage Removal vs. Adsorbent Dosage ( $C_0 = 10 \text{ mg/L}$ )

Figure above shows percentage removal over adsorbent dosage of zinc adsorption with initial concentration of 10 mg/L. The highest percentage removal was 97.5% at 6-hours of adsorption. All of the percentages removal were 90 mg/L and above. Table below shows percentage removal based on adsorption period.

Table 11 Percentage Removal of Zinc based on Adsorption Period ( $C_0 = 10 \text{ mg/L}$ )

Adsorption Period (hr)	Percentage Removal (%)
1	96
3	90
6	98
24	93

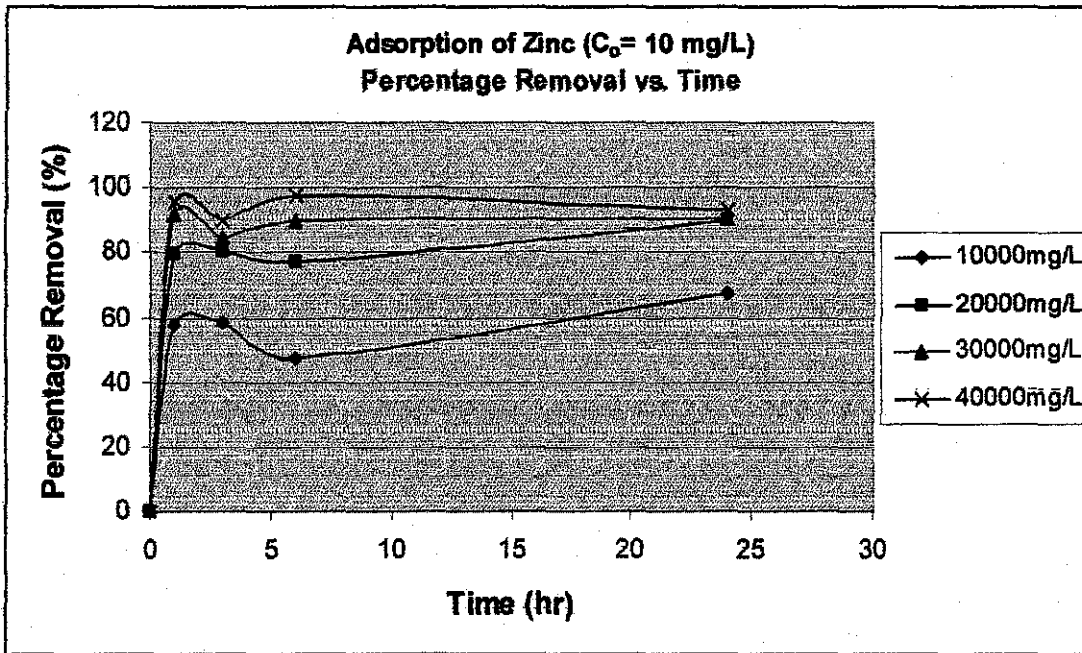


Figure 33 Graph Percentage Removal vs. Time ( $C_0 = 10 \text{ mg/L}$ )

Figure 32 shows percentage removal of zinc over time. As the time increased, the percentage removal increased. However, for 10000 mg/L and 20000 mg/L of adsorbent dosage, the reading decrease after 1 hour of adsorption and gradually increase after 6 hours. Table below shows percentage removal of zinc based on adsorbent dosage.

Table 12 Percentage Removal of Zinc based on Adsorbent Dosage ( $C_0 = 10 \text{ mg/L}$ )

Adsorbent Dosage (mg/L)	Percentage Removal (%)
10000	67
20000	90
30000	90
40000	93

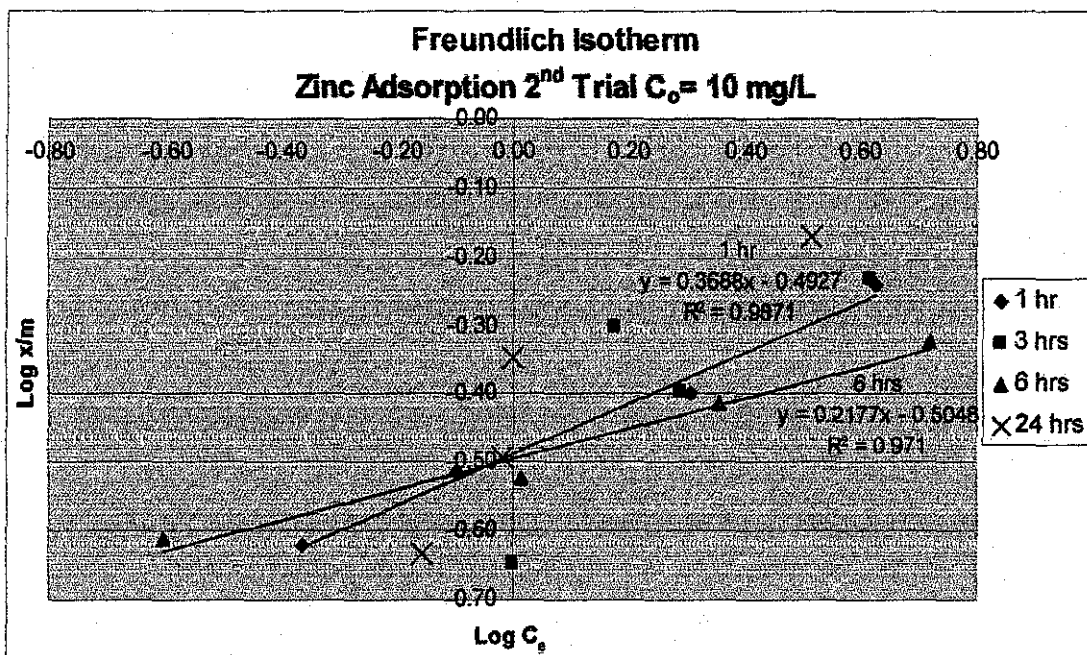
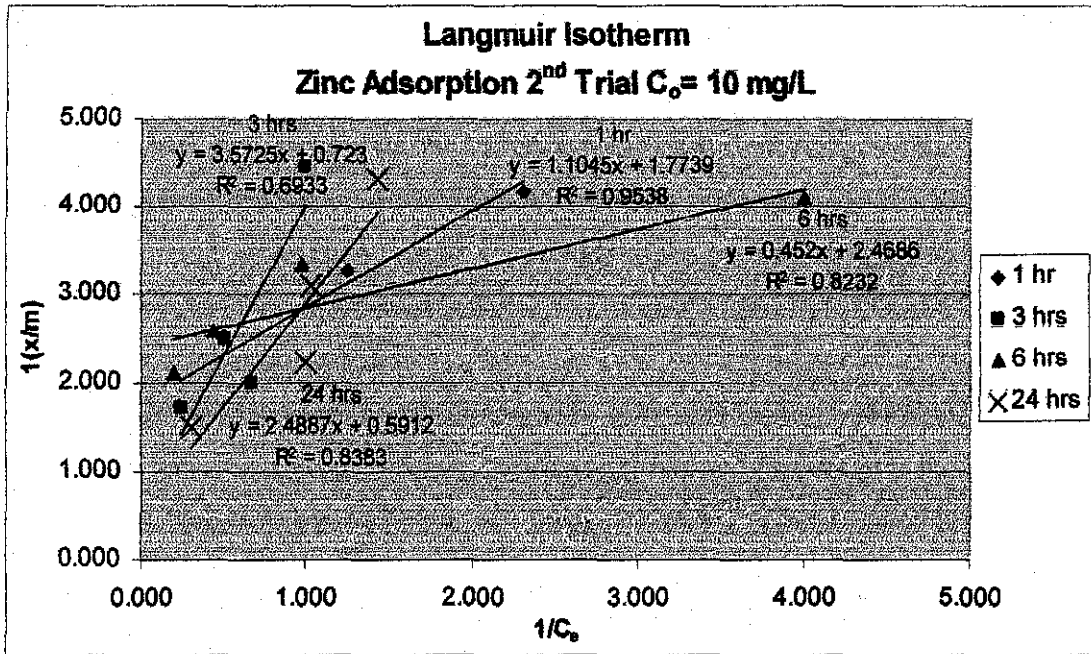


Figure 34 Freundlich Isotherm Model for Zinc Adsorption (C<sub>0</sub> = 10 mg/L)

The figure above shows Freundlich isotherm model for zinc adsorption with initial concentration of 10 mg/L. Only 1 and 6-hour lines were the best fitted line. K<sub>f</sub> values for 1 and 6-hour were  $3.2 \times 10^{-1}$  and  $3.3 \times 10^{-1}$ . Log x/m values were negative based on calculation by using Freundlich isotherm formulae.



**Figure 35 Langmuir isotherm Model for Zinc Adsorption (C<sub>0</sub> = 10 mg/L)**

Based on the above Langmuir isotherm model, all of the fitted lines were following good trend. The R<sup>2</sup> values were ranged from 0.69 to 0.95. The best fit was 1-hour with R<sup>2</sup> value of 0.9538.

## CHAPTER 5

### CONCLUSION

#### 5.1 PHASE 1

There were two trials were done during 1<sup>st</sup> phase of the project. The 1<sup>st</sup> trial was using adsorbent dosage of 25, 50, 100 and 200 mg. While for the 2<sup>nd</sup> trial, the adsorbent dosage used were 25, 50, 75, and 100 mg.

During the first trial, for initial concentration ( $C_0$ ) of 11.45 mg/L, the highest percentage removal was 92.56% with adsorbent dosage of 2000mg/L. The optimum adsorption period (t) was 24 hours with removal capacity of 81.22%. If were compared to Freundlich isotherm, the highest  $K_f$  value was 39.31 at 3 hours of adsorption.

Thus, there was non-conformance between adsorption isotherm and percentage removal for zinc adsorption with  $C_0$  of 11.45 mg/L.

In the 1<sup>st</sup> trial of zinc adsorption with  $C_0$  of 240 mg/L, the highest percentage removal of zinc was 92.56%. The optimum adsorption period (t) was 24 hours with removal capacity of 92.56%. Based on Freundlich isotherm, the highest  $K_f$  value was 17.08 at 24 hours.

Hence it can be said that 24 hours was the optimum adsorption period and 2000mg/L was the optimum adsorbent dosage.

In the 2<sup>nd</sup> trial of phase 1, for  $C_0$  of 141.33, the highest percentage removal of zinc was 41.27% at 6 hours of adsorption. The optimum adsorbent dosage was 1000mg/L with the highest percentage removal of 41.27%. The highest  $K_f$  value in Freundlich isotherm was  $5.27 \times 10^{14}$  at 6 hours of adsorption.



## 5.2 PHASE 2

There were two trials had been done in the 2<sup>nd</sup> phase of the project. The first trial was using 25, 50, 100 and 200 mg of adsorbent dosage. The adsorbent dosages used for the 2<sup>nd</sup> trial were 1000, 2000, 3000, and 4000 mg.

During the first trial, for zinc adsorption with initial concentration ( $C_0$ ) of 10 mg/L, the highest percentage removal was 28% at 3 hours of adsorption. The optimum dosage for zinc adsorption was 2000 mg/L with the highest percentage removal of 21%. Based on Freundlich isotherm, only 3-hour line was accepted with  $K_f$  value of  $2.99 \times 10^{-3}$ .

In the 1<sup>st</sup> trial of zinc adsorption with  $C_0$  of 110 mg/L, the highest percentage removal was 20% at 3 hours. The highest adsorbent dosage was 2000 mg/L with percentage removal of 21%. However, in Freundlich isotherm, only 24-hour line was acceptable with  $K_f$  value of  $1.26 \times 10^{-35}$ . Hence, the experiment should be redone.

During the 2<sup>nd</sup> trial in 2<sup>nd</sup> phase of the project, the highest percentage removal was 97.5% at 6 hours of adsorption. The optimum dosage was 40000 mg/L with the highest percentage removal of 93%. Based on Freundlich isotherm, the 6-hour line was acceptable with  $K_f$  value of  $3.3 \times 10^{-1}$ .

In conclusion, the higher the adsorbent dosage was used, the higher the percentage removal. A good plot of the adsorption isotherm depended on the degree of consistency of the adsorption model.

## **CHAPTER 6**

### **RECOMMENDATION**

#### **6.1 METHODOLOGY**

Towards the improvement of the study, there are several recommendations need to be made on the methodology. The methodology shall be prepared prior to performing the experiment. This will minimize errors and inconsistencies.

Every used apparatus shall be washed properly with soap. This is important in order to get rid the residual particles or any residual zinc on the apparatus that will affect the readings. Every irrelevant reading shall be repeated in order to get a consistent reading.

Every dilution process shall take place in several transitions. For example, in order to dilute from 1000 mg/L to 10 mg/L, the dilution shall undergo dilution concentration from 1000 mg/L to 100 mg/L to 10 mg/L. Direct dilution will deviate the result from desired concentration. Normal pipette shall be used in order to measure volume of solution.

Based on the result, the experiment shall be repeated with new adsorbent dosages. Those dosages are 100, 200, 300, 400, and 500 mg. The contact time shall be reduced from 1 to 6 hours.

Activation of carbon will improve its adsorption capacity and enhance the result of this experiment. The method of activation that will be applied shall be discussed with supervisor.

## CHAPTER 7

### REFERENCES

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## **APPENDICES**

In this experiment, dilution will be performed oftenly. Since zinc will be tested as heavy metals, the dilution theory as below:

Theoretically

In the lab, the only zinc [Zn(II)] available is in the form of zinc chloride (ZnCl<sub>2</sub>).

Molecular weight of ZnCl<sub>2</sub>: 65.409 + 2(35.453) = 136.315

Thus, 136.315 gm of ZnCl<sub>2</sub> contains 65.409 gram of zinc

Using binary equation method,

65.409 gm of Zn = 136.315 gm of ZnCl<sub>2</sub>

1 gm of Zn = 136.315 gm of ZnCl<sub>2</sub> / 65.409 gm of Zn

1 gm of Zn = 2.084 gm of ZnCl<sub>2</sub>

Convert into milligram 1000 mg of Zn = 2084 mg of ZnCl<sub>2</sub>

If dissolved in 1L of solution

1000mg/L of Zn = 2084mg/L of ZnCl<sub>2</sub>

Or 1000ppm of Zn = 2084 mg of ZnCl<sub>2</sub> in 1L of distilled water

To make various solution from stock solution of 1000ppm

$M_1V_1 = M_2V_2$  where  $M_1$  = Molarity of known solution concentration

$M_2$  = Molarity of desired concentration

$V_1$  = Volume of known concentration

$V_2$  = Volume of desired concentration

To prepare 100ppm solution from 1000ppm stock solution,

$1000 \text{ mg/L} \times V_1 = 100\text{mg/L} \times 1000\text{mL}$

$V_1 = 100\text{mL}$

It means that 100mL taken from 1000mg/L of stock solution shall be topped up with 900mL of distilled water. Hence its final concentration will be 100mg/L.

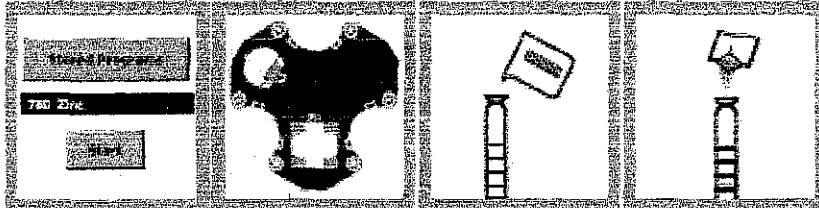
Same method is applied to the preparation of 10ppm solution.

#### Appendix 1 Detailed Calculation of Dilution Process

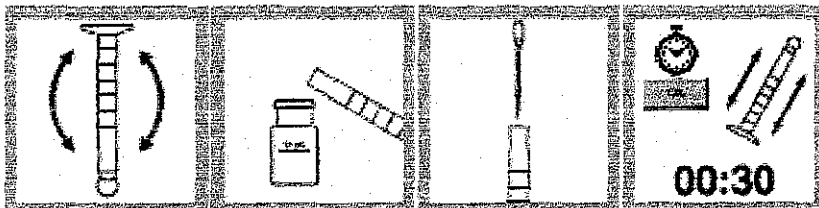
**Zinc (0.01 to 3.00 mg/L)**

**CAUTION**

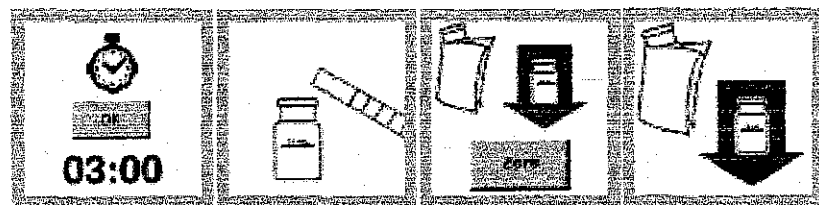
Zinc Ver 5 Reagent contains cyanide and is very poisonous if taken internally or if fumes are inhaled. Do not add to an acidic sample (pH < 4).



1. Select the test.
2. Insert the Multi-cell Adapter with the 1-inch square cell holder facing the user.
3. Fill a 25-mL graduated mixing cylinder with 20 mL of sample.
4. Add the contents of one Zinc Ver 5 Reagent Powder Pillow to the cylinder. Stopper.



5. Invert several times to dissolve the powder completely. Inconsistent readings may result for low zinc concentrations if all the particles are not dissolved.  
  
The sample should be orange. If the sample is brown or blue, either the zinc concentration is too high, or an interfering metal is present. Dilute the sample and repeat the test.
6. Blank Preparation: Pour 10 mL of the solution into a square sample cell.
7. Prepared Sample: Use a plastic dropper to add 0.5 mL of cyclohexanone to the remaining solution in the graduated cylinder.
8. Press TIMER-OK. A 30-second reaction period will begin. During the reaction period stopper the cylinder and vigorously shake the prepared sample. The sample will be reddish-orange, brown, or blue, depending on the zinc concentration.



9. Press TIMER-OK. A three-minute reaction period will begin. During this reaction period, complete step 10.
10. Pour the prepared sample solution from the cylinder into a second square sample cell.
11. When the timer expires, wipe the blank and insert it into the cell holder with the fill line facing the user. Press ZERO. The display will show:  
**0.00 mg/L Zn**
12. Wipe the prepared sample and insert it into the cell holder with the fill line facing the user. Results are in mg/L Zn.

**Appendix 2 HACH Procedure of Zinc Test**

No	Weight of Adsorbent (mg)	Concentration After Adsorption (mg/L)			
		1	2	3	Average
1	25	190	0	150	170
2	50	130	140	0	135
3	100	0	112	143	127.5
4	200	0	130	110	120

Table 13 Equilibrium Concentration;  $C_0 = 11.45$  mg/L;  $t = 1$  hr

No	Weight of Adsorbent (mg)	Concentration After Adsorption (mg/L)			
		1	2	3	Average
1	25	102	0	104	103
2	50	46	33	0	39.5
3	100	49	43	54	48.67
4	200	34	0	33	33.5

Table 14 Equilibrium Concentration;  $C_0 = 11.45$  mg/L;  $t = 3$  hrs

No	Weight of Adsorbent (mg)	Concentration After Adsorption (mg/L)			
		1	2	3	Average
1	25	0	102	127	114.5
2	50	96	92	0	94
3	100	0	68	79	73.5
4	200	0	62	47	54.5

Table 15 Equilibrium Concentration;  $C_0 = 11.45$  mg/L;  $t = 6$  hrs

No	Weight of Adsorbent (mg)	Concentration After Adsorption (mg/L)			
		1	2	3	Average
1	25	0	112	98	105
2	50	0	93	96	94.5
3	100	85	0	89	87
4	200	19	17	0	18

Table 16 Equilibrium Concentration;  $C_0 = 11.45$  mg/L;  $t = 24$  hrs



No	Weight of Adsorbent (mg)	Concentration After Adsorption (mg/L)			
		1	2	3	Average
1	25	3.8	2.7	4.2	3.57
2	50	3	0	3.1	3.05
3	100	0	1.4	1.7	1.55
4	200	8.2	8	8	8.07

Table 17 Equilibrium Concentration;  $C_0 = 245$  mg/L;  $t = 1$  hr

No	Weight of Adsorbent (mg)	Concentration After Adsorption (mg/L)			
		1	2	3	Average
1	25	2.1	2.6	2.2	2.3
2	50	0	1.5	0	1.5
3	100	0	1.4	1.7	1.55
4	200	8.2	8	8	8.07

Table 18 Equilibrium Concentration;  $C_0 = 245$  mg/L;  $t = 3$  hrs

No	Weight of Adsorbent (mg)	Concentration After Adsorption (mg/L)			
		1	2	3	Average
1	25	2.8	0	0	2.8
2	50	2.7	0	3.2	2.95
3	100	0	2.3	0	2.3
4	200	2.4	2.8	0	2.6

Table 19 Equilibrium Concentration;  $C_0 = 245$  mg/L;  $t = 6$  hrs

No	Weight of Adsorbent (mg)	Concentration After Adsorption (mg/L)			
		1	2	3	Average
1	25	2.2	1.8	1.4	1.8
2	50	6.5	8.1	8.9	7.83
3	100	0	4.4	4.9	3.15
4	200	0	2.1	2.2	2.15

Table 20 Equilibrium Concentration;  $C_0 = 245$  mg/L;  $t = 24$  hrs

No	Weight of Adsorbent (mg)	Concentration After Adsorption (mg/L)			
		1	2	3	Average
	$C_0$	94	101	91	95.33
1	25	112	111	105	109.33
2	50	112	103	110	108.33
3	75	113	116	0	105
4	100	101	0	106	103.5

Table 21 Equilibrium Concentration; 2<sup>nd</sup> Trial; t= 1hr

No	Weight of Adsorbent (mg)	Concentration After Adsorption (mg/L)			
		1	2	3	Average
	$C_0$	112	0	116	114
1	25	113	102	0	107.5
2	50	114	103	119	112
3	75	119	113	95	109
4	100	0	102	107	104.5

Table 22 Equilibrium Concentration; 2<sup>nd</sup> Trial; t= 3 hrs

No	Weight of Adsorbent (mg)	Concentration After Adsorption (mg/L)			
		1	2	3	Average
	$C_0$	103	99	95	99
1	25	100	96	97	97.67
2	50	93	95	93	93.67
3	75	85	89	87	87
4	100	87	82	80	83

Table 23 Equilibrium Concentration; 2<sup>nd</sup> Trial; t= 6 hrs

No	Weight of Adsorbent (mg)	Concentration After Adsorption (mg/L)			
		1	2	3	Average
	$C_0$	138	141	145	141.33
1	25	123	127	125	125
2	50	105	92	92	96.33
3	75	0	117	112	114.5
4	100	0	99	72	85.5

Table 24 Equilibrium Concentration, 2<sup>nd</sup> Trial; t= 24 hrs

Weight of Adsorbent (mg)	Concentration After Adsorption (mg/L)				$\frac{x}{C_0} \cdot 100/1000$	$(C_0 - C_e)$	x/m (mg/g)	log (x/m)	log C
	1	2	3	$C_e$					
25	190	0	150	170	7.00	280.00	2.45	2.23	
50	130	140	0	135	10.50	210.00	2.32	2.13	
100	0	112	143	127.5	11.25	112.50	2.05	2.11	
200	0	130	110	120	12.00	60.00	1.78	2.08	

Table 25 Freundlich Model Calculation; 1<sup>st</sup> Trial;  $C_0 = 240$  mg/L;  $t = 1$  hr

Weight of Adsorbent (mg)	Concentration After Adsorption (mg/L)				$\frac{x}{C_0} \cdot 100/1000$	$(C_0 - C_e)$	x/m (mg/g)	log (x/m)	log C
	1	2	3	$C_e$					
25	102	0	104	103	13.70	548.00	2.74	2.01	
50	46	33	0	39.5	20.05	401.00	2.60	1.60	
100	49	43	54	48.67	19.13	191.33	2.28	1.66	
200	34	0	33	33.5	20.65	103.25	2.01	1.53	

Table 26 Freundlich Model Calculation; 1<sup>st</sup> Trial;  $C_0 = 240$  mg/L;  $t = 3$  hrs

Weight of Adsorbent (mg)	Concentration After Adsorption (mg/L)				$\frac{x}{C_0} \cdot 100/1000$	$(C_0 - C_e)$	x/m (mg/g)	log (x/m)	log C
	1	2	3	$C_e$					
25	0	102	127	114.5	12.55	502.00	2.70	2.06	
50	96	92	0	94	14.60	292.00	2.47	1.97	
100	0	68	79	73.5	16.65	166.50	2.22	1.87	
200	0	62	47	54.5	18.55	92.75	1.97	1.74	

Table 27 Freundlich Model Calculation; 1<sup>st</sup> Trial;  $C_0 = 240$  mg/L;  $t = 6$  hrs

Weight of Adsorbent (mg)	Concentration After Adsorption (mg/L)				$\frac{x}{C_0} \cdot 100/1000$	$(C_0 - C_e)$	x/m (mg/g)	log (x/m)	log C
	1	2	3	$C_e$					
25	0	112	98	105	13.50	540.00	2.73	2.0	
50	0	93	96	94.5	14.55	291.00	2.46	1.9	
100	85	0	89	87	15.30	153.00	2.18	1.9	
200	19	17	0	18	22.20	111.00	2.05	1.2	

Table 28 Freundlich Model Calculation; 1<sup>st</sup> Trial;  $C_0 = 240$  mg/L;  $t = 24$  hrs

Weight of Adsorbent (mg)	Concentration After Adsorption (mg/L)				$\frac{x}{C_e} \cdot 100/1000$	$(C_e)$	x/m (mg/g)	1/C <sub>e</sub> (L/mg)	1/(x/m)
	1	2	3	C <sub>e</sub>					
25	190	0	150	170	7.00	280.00	0.0059	0.003	
50	130	140	0	135	10.50	210.00	0.0074	0.004	
100	0	112	143	127.5	11.25	112.50	0.0078	0.008	
200	0	130	110	120	12.00	60.00	0.0083	0.016	

Table 29 Langmuir Model Calculation; 1<sup>st</sup> Trial; C<sub>0</sub>= 240 mg/L; t= 1hr

Weight of Adsorbent (mg)	Concentration After Adsorption (mg/L)				$\frac{x}{C_e} \cdot 100/1000$	$(C_e)$	x/m (mg/g)	1/C <sub>e</sub> (L/mg)	1/(x/m)
	1	2	3	C <sub>e</sub>					
25	102	0	104	103	13.70	548.00	0.0097	0.00	
50	46	33	0	39.5	20.05	401.00	0.0253	0.00	
100	49	43	54	48.67	19.13	191.33	0.0205	0.01	
200	34	0	33	33.5	20.65	103.25	0.0299	0.01	

Table 30 Langmuir Model Calculation; 1<sup>st</sup> Trial; C<sub>0</sub>= 240 mg/L; t= 3hrs

Weight of Adsorbent (mg)	Concentration After Adsorption (mg/L)				$\frac{x}{C_e} \cdot 100/1000$	$(C_e)$	x/m (mg/g)	1/C <sub>e</sub> (L/mg)	1/(x/m)
	1	2	3	C <sub>e</sub>					
25	0	102	127	114.5	12.55	502.00	0.0087	0.00	
50	96	92	0	94	14.60	292.00	0.0106	0.00	
100	0	68	79	73.5	16.65	166.50	0.0136	0.01	
200	0	62	47	54.5	18.55	92.75	0.0183	0.01	

Table 31 Langmuir Model Calculation; 1<sup>st</sup> Trial; C<sub>0</sub>= 240 mg/L; t= 6hrs

Weight of Adsorbent (mg)	Concentration After Adsorption (mg/L)				$\frac{x}{C_e} \cdot 100/1000$	$(C_e)$	x/m (mg/g)	1/C <sub>e</sub> (L/mg)	1/(x/m)
	1	2	3	C <sub>e</sub>					
25	0	112	98	105	13.50	540.00	0.0095	0.00	
50	0	93	96	94.5	14.55	291.00	0.0106	0.00	
100	85	0	89	87	15.30	153.00	0.0115	0.01	
200	19	17	0	18	22.20	111.00	0.0556	0.01	

Table 32 Langmuir Model Calculation; 1<sup>st</sup> Trial; C<sub>0</sub>= 240 mg/L; t= 24 hrs

Weight of Adsorbent (mg)	Concentration After Adsorption (mg/L)				$x = \frac{C_e}{C_0} \cdot 100/1000$	$(C_e)$	$x/m$ (mg/g)	$\log(x/m)$	$\log C_e$
	1	2	3	$C_e$					
25	3.8	2.7	4.2	3.57	0.79	31.53	1.50	0.55	
50	3	0	3.1	3.05	0.84	16.80	1.23	0.48	
100	0	1.4	1.7	1.55	0.99	9.90	1.00	0.19	
200	8.2	8	8	8.07	0.34	1.69	0.23	0.91	

Table 33 Freundlich Model Calculation; 1<sup>st</sup> Trial;  $C_0 = 11.45$  mg/L;  $t = 1$  hr

Weight of Adsorbent (mg)	Concentration After Adsorption (mg/L)				$x = \frac{C_e}{C_0} \cdot 100/1000$	$(C_e)$	$x/m$ (mg/g)	$\log(x/m)$	$\log C_e$
	1	2	3	$C_e$					
25	2.1	2.6	2.2	2.3	0.92	36.60	1.56	0.36	
50	0	1.5	0	1.5	1.07	21.40	1.33	0.18	
100	0	1.4	1.7	1.55	0.99	9.90	1.00	0.19	
200	8.2	8	8	8.07	0.34	1.69	0.23	0.91	

Table 34 Freundlich Model Calculation; 1<sup>st</sup> Trial;  $C_0 = 11.45$  mg/L;  $t = 3$  hrs

Weight of Adsorbent (mg)	Concentration After Adsorption (mg/L)				$x = \frac{C_e}{C_0} \cdot 100/1000$	$(C_e)$	$x/m$ (mg/g)	$\log(x/m)$	$\log C_e$
	1	2	3	$C_e$					
25	2.8	0	0	2.8	0.87	34.60	1.54	0.45	
50	2.7	0	3.2	2.95	0.85	17.00	1.23	0.47	
100	0	2.3	0	2.3	0.92	9.15	0.96	0.36	
200	2.4	2.8	0	2.6	0.89	4.43	0.65	0.41	

Table 35 Freundlich Model Calculation; 1<sup>st</sup> Trial;  $C_0 = 11.45$  mg/L;  $t = 6$  hrs

Weight of Adsorbent (mg)	Concentration After Adsorption (mg/L)				$x = \frac{C_e}{C_0} \cdot 100/1000$	$(C_e)$	$x/m$ (mg/g)	$\log(x/m)$	$\log C_e$
	1	2	3	$C_e$					
25	2.2	1.8	1.4	1.8	0.97	38.60	1.59	0.2	
50	6.5	8.1	8.9	7.83	0.36	7.23	0.86	0.8	
100	0	4.4	4.9	3.15	0.68	6.80	0.83	0.5	
200	0	2.1	2.2	2.15	0.93	4.65	0.67	0.5	

Table 36 Freundlich Model Calculation; 1<sup>st</sup> Trial;  $C_0 = 11.45$  mg/L;  $t = 24$  hrs

Weight of Adsorbent (mg)	Concentration After Adsorption (mg/L)				$\frac{x}{C_e} \times 100/1000$	$(C_e)$	x/m (mg/g)	1/C <sub>e</sub> (L/mg)	1/(x/m)
	1	2	3	C <sub>e</sub>					
25	3.8	2.7	4.2	3.57	0.79	31.53	0.28	0.03	
50	3	0	3.1	3.05	0.84	16.80	0.33	0.06	
100	0	1.4	1.7	1.55	0.99	9.90	0.65	0.10	
200	8.2	8	8	8.07	0.34	1.69	0.12	0.59	

Table 37 Langmuir Model Calculation; 1<sup>st</sup> Trial; C<sub>0</sub> = 11.45 mg/L; t = 1hr

Weight of Adsorbent (mg)	Concentration After Adsorption (mg/L)				$\frac{x}{C_e} \times 100/1000$	$(C_e)$	x/m (mg/g)	1/C <sub>e</sub> (L/mg)	1/(x/m)
	1	2	3	C <sub>e</sub>					
25	2.1	2.6	2.2	2.3	0.92	36.60	0.43	0.03	
50	0	1.5	0	1.5	1.07	21.40	0.67	0.05	
100	0	1.4	1.7	1.55	0.99	9.90	0.65	0.10	
200	8.2	8	8	8.07	0.34	1.69	0.12	0.59	

Table 38 Langmuir Model Calculation; 1<sup>st</sup> Trial; C<sub>0</sub> = 11.45 mg/L; t = 3hrs

Weight of Adsorbent (mg)	Concentration After Adsorption (mg/L)				$\frac{x}{C_e} \times 100/1000$	$(C_e)$	x/m (mg/g)	1/C <sub>e</sub> (L/mg)	1/(x/m)
	1	2	3	C <sub>e</sub>					
25	2.8	0	0	2.8	0.87	34.60	0.36	0.0	
50	2.7	0	3.2	2.95	0.85	17.00	0.34	0.0	
100	0	2.3	0	2.3	0.92	9.15	0.43	0.1	
200	2.4	2.8	0	2.6	0.89	4.43	0.38	0.2	

Table 39 Langmuir Model Calculation; 1<sup>st</sup> Trial; C<sub>0</sub> = 11.45 mg/L; t = 6hrs

Weight of Adsorbent (mg)	Concentration After Adsorption (mg/L)				$\frac{x}{C_e} \times 100/1000$	$(C_e)$	x/m (mg/g)	1/C <sub>e</sub> (L/mg)	1/(x/m)
	1	2	3	C <sub>e</sub>					
25	2.2	1.8	1.4	1.8	0.97	38.60	0.56	0.0	
50	6.5	8.1	8.9	7.83	0.36	7.23	0.13	0.1	
100	0	4.4	4.9	3.15	0.68	6.80	0.32	0.1	
200	0	2.1	2.2	2.15	0.93	4.65	0.47	0.2	

Table 40 Langmuir Model Calculation; 1<sup>st</sup> Trial; C<sub>0</sub> = 11.45 mg/L; t = 24hrs



Weight of Adsorbent (mg)	Concentration After Adsorption (mg/L)				$\frac{x}{C_0} \cdot 100/1000$ ( $C_0$ )	x/m (mg/g)	log (x/m)	log $C_0$
	1	2	3	Average				
$C_0$	94	101	91	95.33				
25	112	111	105	109.33				
50	112	103	110	108.33				
75	113	116	0	105				
100	101	0	106	103.5				

Table 41 Freundlich Model Calculation; 2<sup>nd</sup> Trial; t= 1hr

Weight of Adsorbent (mg)	Concentration After Adsorption (mg/L)				$\frac{x}{C_0} \cdot 100/1000$ ( $C_0$ )	x/m (mg/g)	log (x/m)	log $C_0$
	1	2	3	Average				
$C_0$	112	0	116	114				
25	113	102	0	107.5	0.65	26.00	1.41	2.00
50	114	103	119	112	0.20	4.00	0.60	2.00
75	119	113	95	109	0.50	6.67	0.82	2.00
100	0	102	107	104.5	0.95	9.50	0.98	2.00

Table 42 Freundlich Model Calculation; 2<sup>nd</sup> Trial; t= 3hrs

Weight of Adsorbent (mg)	Concentration After Adsorption (mg/L)				$\frac{x}{C_0} \cdot 100/1000$ ( $C_0$ )	x/m (mg/g)	log (x/m)	log $C_0$
	1	2	3	Average				
$C_0$	103	99	95	99				
25	100	96	97	97.67	0.13	5.33	0.73	1.99
50	93	95	93	93.67	0.53	10.67	1.03	1.97
75	85	89	87	87	1.20	16.00	1.20	1.94
100	87	82	80	83	1.60	16.00	1.20	1.92

Table 43 Freundlich Model Calculation; 2<sup>nd</sup> Trial; t= 6hrs

Weight of Adsorbent (mg)	Concentration After Adsorption (mg/L)				$\frac{x}{C_0} \cdot 100/1000$ ( $C_0$ )	x/m (mg/g)	log (x/m)	log $C_0$
	1	2	3	Average				
$C_0$	138	141	145	141.33				
25	123	127	125	125	1.63	65.32	1.82	2.00
50	105	92	92	96.33	4.50	89.99	1.95	1.99
75	0	117	112	114.5	2.68	35.77	1.55	2.00
100	0	99	72	85.5	5.58	55.83	1.75	1.99

Table 44 Freundlich Model Calculation; 2<sup>nd</sup> Trial; t= 24hrs

Weight of Adsorbent (mg)	Concentration After Adsorption (mg/L)				$\frac{x}{C_e} \cdot 100/1000$	$(C_e)$	$x/m$ (mg/g)	$1/C_e$ (L/mg)	$1/(x/m)$
	1	2	3	Average					
$C_0$	94	101	91	95.33					
25	112	111	105	109.33					
50	112	103	110	108.33					
75	113	116	0	105					
100	101	0	106	103.5					

Table 45 Langmuir Model Calculation; 2<sup>nd</sup> Trial; t= 1hr

Weight of Adsorbent (mg)	Concentration After Adsorption (mg/L)				$\frac{x}{C_e} \cdot 100/1000$	$(C_e)$	$x/m$ (mg/g)	$1/C_e$ (L/mg)	$1/(x/m)$
	1	2	3	Average					
$C_0$	112	0	116	114					
25	113	102	0	107.5	0.65	26.00	0.00930	0.05	
50	114	103	119	112	0.20	4.00	0.00893	0.25	
75	119	113	95	109	0.50	6.67	0.00917	0.11	
100	0	102	107	104.5	0.95	9.50	0.00957	0.11	

Table 46 Langmuir Model Calculation; 2<sup>nd</sup> Trial; t= 3hrs

Weight of Adsorbent (mg)	Concentration After Adsorption (mg/L)				$\frac{x}{C_e} \cdot 100/1000$	$(C_e)$	$x/m$ (mg/g)	$1/C_e$ (L/mg)	$1/(x/m)$
	1	2	3	Average					
$C_0$	103	99	95	99					
25	100	96	97	97.67	0.13	5.33	0.01024	0.11	
50	93	95	93	93.67	0.53	10.67	0.01068	0.09	
75	85	89	87	87	1.20	16.00	0.01149	0.09	
100	87	82	80	83	1.60	16.00	0.01205	0.09	

Table 47 Langmuir Model Calculation; 2<sup>nd</sup> Trial; t= 6hrs

Weight of Adsorbent (mg)	Concentration After Adsorption (mg/L)				$\frac{x}{C_e} \cdot 100/1000$	$(C_e)$	$x/m$ (mg/g)	$1/C_e$ (L/mg)	$1/(x/m)$
	1	2	3	Average					
$C_0$	138	141	145	141.33					
25	123	127	125	125	1.63	65.32	0.00800	0.09	
50	105	92	92	96.33	4.50	89.99	0.01038	0.09	
75	0	117	112	114.5	2.68	35.77	0.00873	0.09	
100	0	99	72	85.5	5.58	55.83	0.01170	0.09	

Table 48 Langmuir Model Calculation; 2<sup>nd</sup> Trial; t= 24hrs



Freundlich Isotherm								
C <sub>0</sub>	11.45 mg/L				240 mg/L			
t	1	3	6	24	1	3	6	24
Parameter								
R <sup>2</sup>	0.3751	0.6605	0.2903	0.1683	0.7527	0.5333	0.9944	0.5543
1/n	-1.1084	-1.3823	0.2903	0.5895	3.9079	1.105	2.26	0.6252
K <sub>f</sub> (L/mg)	37.88	39.31	0.17	18.98	6.3x10 <sup>-7</sup>	3.35	0.01	17.08

Table 49 Freundlich Isotherm's Important Parameters; 1<sup>st</sup> Trial

Freundlich Isotherm			
T	3	6	24
Parameter			
R <sup>2</sup>	0.324	0.8314	0.0671
1/n	-15.598	-6.4749	2.9434
K <sub>f</sub> (L/mg)	4.8x10 <sup>32</sup>	5x10 <sup>13</sup>	877.81

Table 50 Freundlich Isotherm's Important Parameters; 2<sup>nd</sup> Trial

Weight of Adsorbent (mg)	Concentration After Adsorption (mg/L)				$x = \frac{(C_0 - C_e) \cdot 100}{1000}$	x/m (mg/g)	log (x/m)	log C <sub>e</sub>	1/C <sub>e</sub> (L/mg)	1/(x/m)
	1	2	3	Average						
25		9.8		9.80	0.003	0.12	-0.921	0.9912	0.102041	8.333333
50			9.2	9.2	0.063	1.26	0.100	0.9638	0.108696	0.793651
100	9			9	0.083	0.83	-0.081	0.9542	0.111111	1.204819
200		8.6		8.6	0.123	0.615	-0.211	0.9345	0.116279	1.626016

Table 51 Phase 2 1<sup>st</sup> Trial C<sub>0</sub> = 10 ppm (t = 1 hr)

Weight of Adsorbent (mg)	Concentration After Adsorption (mg/L)				$x = \frac{(C_0 - C_e) \cdot 100}{1000}$	x/m (mg/g)	log (x/m)	log C <sub>e</sub>	1/C <sub>e</sub> (L/mg)	1/(x/m)
	1	2	3	Average						
25		9.1		9.10	0.083	3.32	0.5211	0.9590	0.110	0.301
50			8.9	8.9	0.103	2.06	0.3139	0.9494	0.112	0.485
100		8.2	8.1	8.15	0.178	1.78	0.2504	0.9112	0.123	0.562
200	7.2			7.2	0.273	1.365	0.1351	0.8573	0.139	0.733

Table 52 Phase 2 1<sup>st</sup> Trial C<sub>0</sub> = 10 ppm (t = 3 hrs)

Weight of Adsorbent	Concentration After Adsorption (mg/L)				$x = \frac{(C_0 - C_e) \cdot 100}{1000}$	x/m (mg/g)	log (x/m)	log C <sub>e</sub>	1/C <sub>e</sub> (L/mg)	1/(x/m)
	1	2	3	Average						
25		8.5	8.5	8.50	0.09	3.6	0.5563	0.9294	0.117647	0.277778
50			8.3	8.3	0.11	2.2	0.3424	0.9191	0.120482	0.454545
100		7.9		7.9	0.15	1.5	0.1761	0.8976	0.126582	0.666667
200			7.5	7.5	0.19	0.95	-0.022	0.8751	0.133333	1.052632

Table 53 Phase 2 1<sup>st</sup> Trial C<sub>0</sub> = 10 ppm (t = 6 hrs)

Weight of Adsorbent	Concentration After Adsorption (mg/L)				$x = \frac{(C_0 - C_e) \cdot 100}{1000}$	x/m (mg/g)	log (x/m)	log C <sub>e</sub>	1/C <sub>e</sub> (L/mg)	1/(x/m)
	1	2	3	Average						
25		9.7	9.7	9.70	0.035	1.4	0.1461	0.9868	0.103	0.714
50	9.4	9.4		9.4	0.065	1.3	0.1139	0.9731	0.106	0.769
100	9.3			9.3	0.075	0.75	-0.1249	0.9685	0.108	1.333
200			9.2	9.2	0.085	0.425	-0.3716	0.9638	0.109	2.353

Table 54 Phase 2 1<sup>st</sup> Trial C<sub>0</sub> = 10 ppm (t = 24 hrs)

Weight of Adsorbent (mg)	Concentration After Adsorption (mg/L)				$x = \frac{C_a}{C_o} \cdot 100/1000$	$C_a$ (mg/L)	$x/m$ (mg/g)	$\log(x/m)$	$\log C_o$	$1/C_o$ (L/mg)	$1/(x/m)$
	1	2	3	Average							
1000	4.4	4.2	4.1	4.23	0.57	0.57	-0.247	0.6267	0.236	1.765	
2000	2.2	2.3	1.6	2.03	0.79	0.39	-0.405	0.3082	0.492	2.542	
3000	0.5	0.9	1	0.80	0.91	0.30	-0.518	-0.0969	1.250	3.297	
4000	0.3	0.6	0.4	0.43	0.95	0.24	-0.626	-0.3632	2.308	4.225	

Table 55 Phase 2 2<sup>nd</sup> Trial  $C_o = 10$  ppm (t=1 hr)

Weight of Adsorbent (mg)	Concentration After Adsorption (mg/L)				$x = (C_o - C_a) \cdot 100/1000$	$x/m$ (mg/g)	$\log(x/m)$	$\log C_o$	$1/C_o$ (L/mg)	$1/(x/m)$
	1	2	3	Average						
1000	4.2	4	4.2	4.13	0.51	0.51	-0.2910	0.6163	0.242	1.954
2000	2.3	1.6		1.95	0.73	0.37	-0.4377	0.2900	0.513	2.740
3000	1.9		1.1	1.5	0.78	0.5	-0.3010	0.1761	0.667	2.000
4000	0.9	1	1.1	1	0.83	0.21	-0.6856	0.0000	1.000	4.848

Table 56 Phase 2 2<sup>nd</sup> Trial  $C_o = 10$  ppm (t=3 hrs)

Weight of Adsorbent (mg)	Concentration After Adsorption (mg/L)				$x = \frac{C_a}{C_o} \cdot 100/1000$	$C_a$ (mg/L)	$x/m$ (mg/g)	$\log(x/m)$	$\log C_o$	$1/C_o$ (L/mg)	$1/(x/m)$
	1	2	3	Average							
1000	4.8	5.5	5.4	5.23	0.46	0.46	-0.3376	0.7188	0.191	2.175	
2000	2.4	2.3	2.1	2.27	0.76	0.38	-0.4223	0.3554	0.441	2.644	
3000	0.9	1.1	1.1	1.03	0.88	0.29	-0.5328	0.0142	0.968	3.410	
4000	0.3	0.2		0.25	0.96	0.24	-0.6207	-0.6021	4.000	4.175	

Table 57 Phase 2 2<sup>nd</sup> Trial  $C_o = 10$  ppm (t=6 hrs)

Time of Adsorbent	Concentration After Adsorption (mg/L)				$x = (C_0 - C_e) \cdot 100 / 1000$	$x/m$ (mg/g)	log ( $x/m$ )	log $C_e$	$1/C_e$ (L/mg)	$1/(x/m)$
	1	2	3	Average						
000	3.1	2.9	3.8	3.27	0.610333333	0.61	-0.2144	0.5141	0.306	1.638
000	0.8	1	1.2	1.00	0.837	0.42	-0.3783	0.0000	1.000	2.389
000	1	1	0.9	0.97	0.840333333	0.32	-0.4918	-0.0147	1.034	3.103
000	0.7	0.6	0.8	0.7	0.867	0.22	-0.6540	-0.1549	1.429	4.514

Table 58 Phase 2 2<sup>nd</sup> Trial  $C_0 = 10$  ppm ( $t = 24$  hrs)