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THE STUDY ON CAPABILITY OF PEAT AS CATION EXCHANGER

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entitled

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ผลที่ได้จาก Adsorption isotherm ยืนยันว่าพืที่มี adsorption capability ดินชุดนราธิวาสหมายเลข 21 และ 23 แสดง adsorption capability ที่มีกับแคดเมียมและคอปเปอร์ โดยสามารถกำจัดโลหะดังกล่าวให้มีความเข้มข้นที่ 0.03 และ 1.00 ppm ตามมาตรฐานน้ำทิ้งโรงงานอุตสาหกรรมได้ และจากการคำนวณโดยใช้ Adams and Bohart's equation แสดงให้เห็นว่าพืที่มีความสามารถที่จะใช้เพื่อกำจัดโลหะหนักได้ที่ระดับหนึ่ง อย่างไรก็ตามในทางปฏิบัติค่อนข้างจะไม่สะดวกที่จะใช้พืเป็นตัวดูดซับโลหะในคอลัมน์ เนื่องจากพือาจต้องถูก regenerate ทุก ๆ 2 ชั่วโมง และแม้ว่าการเพิ่มความสูงของคอลัมน์จะช่วยเพิ่มประสิทธิภาพของคอลัมน์ได้ก็ตาม แต่จำเป็นต้องนำเอาเรื่องของ capacity loss อันเนื่องมาจากความสูงวิกฤติ และ adsorptive capacity ของพืมาพิจารณาด้วย ดังนั้นจึงควรจะได้มีการศึกษาเกี่ยวกับ physical factors ซึ่งจะมีผลต่อคอลัมน์พืในอนาคตต่อไปด้วย

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ABSTRACT

This work has involved the study on capability of peat as cation exchanger in continuous column. The main objective is to investigate whether peat is feasible for using as cation exchanger column for heavy metals removal and also the factor effecting to enlarge cation exchanger column of peat. Adsorption isotherm has been carried out using cadmium and copper solution of 50 ppm with up to 9 selected peat samples. Column test has also been performed using the selected peat with best adsorption capability. The glass column ( $\phi$  1.8 x 30 cm) and three different flow rate have been applied. The samples were

collected and analysed using Atomic Absorption Spectrophotometer. The results of service time and bed-height were plotted, and then were calculated using Adams and Bohart's equation.

Adsorption isotherm results confirmed that peat has adsorption capability. The Narathiwat soil series no. 21 and 23 showed their adsorption capability on cadmium and copper, taking a reasonable service time to meet the industrial waste water standard of 0.03 and 1.00 ppm respectively. And the calculated results using applied Adams and Bohart's equation showed that peat is capable to some extent for heavy metal removal. However, in practice it is rather inconvenient to use it as cation exchanger column as peat regeneration may be required at every 2 hours. Eventhough, increasing bed-height to increase column efficiency can be done but capacity loss due to critical bed depth and adsorptive capacity of peat must be taken into consideration. Therefore, the influence of physical factors that effecting peat column should be further investigated.

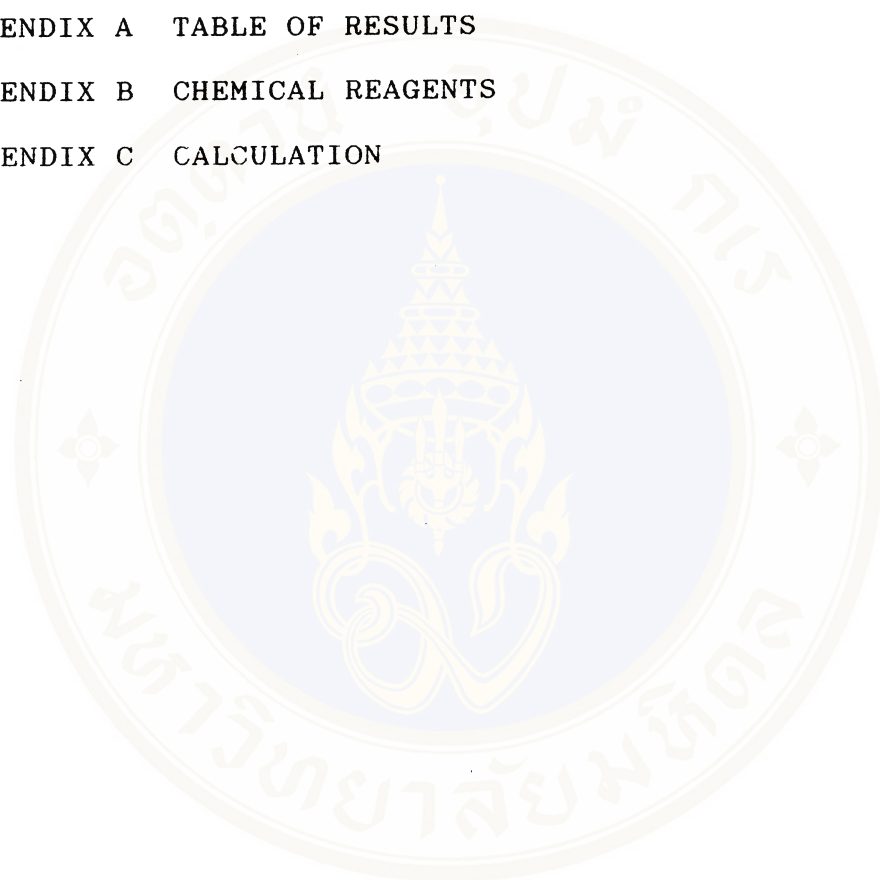
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CHAPTER I  
INTRODUCTION

1.1 Significance of Problem and Trends

Peat is one kind of nonrenewable resource, which comprise of 282,900 rai in Thailand. Almost 60 % (166,250 rai) of them occupied the swampy areas of the east coast in Narathiwat province (1). It has been reported that there are two major peat swamps (2) as follow:

- Todaeng swamp (125,991 rai) is partly in Amphoe Sungai-Padi, Sungai-Kolok and Tak-bai. Some area of this swamp has water-level almost 50 cm and is undrained.

- Bacho swamp (7,300 rai) is partly in Amphoe Bacho, Yi-ngo and Muang. Almost of peat area in this swamp is drained for agricultural purpose.

Amount of peat soils can be decreased upon utilization and peat layer can also be disappeared due to burning and subsidence. Many projects have been established for developing the use of peatland. According to development scheme, a committee of the Phikulthong Education and Development Center has classified peatland into three types as followed:

- Development zone; The area is about 97,465

rai. The most of this zone has been evacuated and some area was allocated to the people for cultivation.

- Conservation zone; The area is about 122,286 rai. Most of the area has been disturbed and natural forestry has been destroyed. This required for being retained in natural condition.

- Preservation zone; Natural forestry and undisturbed area has been found. It is about 59,941 rai.

However, it has been shown that peatland is considerably unsuitable for most kinds of agriculture. So the uses of peat soil from peatland should be considered for other purposes. The utilization of peat for industrial purposes has been researched and developed in many ways in Europe and America. Peat can be used as adsorbent and cation exchangers because of the exchange properties of carboxylic and phenolic groups in the fraction of lignin and humus in peat composition. Mutsuda and Mizumaki (3, 4) reported that peat has also been used in air and waste water treatment process.

## 1.2 Conceptual Idea of the Study

The basic information of peat was considered for choosing the way to develop peat resource and to use for other purposes. Tongcumpou reported that peat from any swamp in Narathiwat province had high percentage in lignin and humic acid fraction (5). Lignin and humic acid have phenolic and carboxylic functional group, which have ion exchangeable and adsorption properties. From this reason, Tongcumpou investigated the way to use peat as cation exchanger or adsorbent (6). The study on laboratory scale gave results that confirmed the feasibility further study on using peat as adsorbent for industry the data showed that peat has considerably potential for the removal of cationic species, especially, heavy metals from water over a wide range of concentrations. So it is reasonable to conduct this research investigating the way to use peat as cation exchanger column. Column operation is one type of operating method of cation exchange. It is similar to a series of batch equilibrium, and is much favoured among the three types of operating. Because ion exchange processes are equilibrium reactions necessitating a continuous contact of the

exchanger with fresh electrolyte in order to drive the reaction to completion.

The study on sulfonated coal by Dorfner found that sulfuric acid enhanced their exchangeable properties (7). For sulfonated coal occurs via sulfonic groups introduced into the coal by the action of the sulfuric acid. In contrast, Tongcumpou's found that sulfuric treatment of peat did not give significantly effect to adsorption capacity. However, the use of untreated peat should be evaluated cost-wise cost select the more economically feasible plan. So untreated peat is used in this research for supporting this reason.

Adsorption is the process primarily used for removal of nonpolar materials and some specific toxic ions. Basically, the process of ion exchange is similar to adsorption system in which a solid, usually porous particle with reactive sites on its surface, come to equilibrium with ion in solution. According to the toxicity of heavy metal, such as Cadmium and Copper and the possibility of peat as cation exchanger have made this research usable for adding value of peat.

### 1.3 Objective of the Study

The major objective of this work is to investigate whether peat is feasible for using as cation exchanger for heavy metals removal. This work is, therefore, carried out in order to study on the capability of peat as cation exchanger column and also study the factor effecting to enlarge cation exchanger column of peat for industry.

### 1.4 Scopes of the Study

This work has been carried out in collaboration with Department of Land Development, Ministry of Agricultural and Cooperative, and is confirmed as followed:

1. Peat samples in this work are collected from Bacho and Todaeng swamps, both in Development and Conservation zone. All samples are taken from Narathiwat and Kabdaeng soil series.

However, the desirable sampling sites are selected with the consideration of soil series, landuse and the access to the area.

2. The composited peat sample, is also desirable the properties of peat in adsorption

isotherm test.

3. The heavy metals used are cadmium and copper which prepared from tri-cadmium sulfate octa hydrate ( $3\text{CdSO}_4 \cdot 5\text{H}_2\text{O}$ ) and copper sulfate penta hydrate ( $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ ) respectively.

4. Glass column with 1.8 cm I.D., 30 cm height is used.

#### 1.5 Significance of the Study

From this study it is expected that : the results will be basic information necessary for using peat as cation exchanger. In addition, it will be an alternative way of developing the natural resource which is ineffective in agricultural utilization to industrial utilization.

## CHAPTER II

### REVIEW OF LITERATURE

#### 2.1 Basic Information of Peat

##### 2.1.1 Source and Definition

Peat is a soil composed of partially decomposed organic matter and inorganic minerals that have accumulated in a water over a period of time (8). The portion that is not water usually only about 10-20 % of the mass is the partially decomposed residue of dead plants. Composition ratio of carbon, hydrogen and oxygen of peat are about 50.0, 6.0 and 44.0 respectively and its color can vary from yellow to brownish black, depend upon the degree of biological decay. Peat is usually found in tropical and temperate zones. The composition of peat depend on climate of peat formation. Waksman explained that basic factors, such as climate of water and soil and its relation, have effected to nature of peat (9). The formation of peat are often found in fresh water swamp forest. High moisture levels establish the necessary anaerobic environment that reduces the exchange of gases which occur for normal biological and chemical decomposition of the organic material.

The rate of peat formation is extremely slow and varies between peatland. Climate and vegetation are primary cause of the variation. Dent (10), Vijarnsorn (11) and Hastings (12) reported that the formation of the swamps in Narathiwat province are related to the geomorphological phenomena of the emergence shoreline. During the period of 5,000 to 3,800 yrs. B.P., the sea began to regress which can be led to the development of progadational lagoons and beaches. In addition, some main streams were also emerged into the tidal flat system, forming unique back swamps between the lower stretches of the main river course. As soon as the lagoons and back swamps were closed, the water become stagnant and the sediments were settled down. By dilution of the sea water with rains, the water was favorable for development of water herbaceous plants. After sufficient organic residues were hoarded, and the swamp became shallower, the native plants gradually changed to the mixed swamp forest types. Finally, the whole swamp have been occupied by the typical fresh water swamp forest that consist of more than 100 genera including trees, palms, climbers, herbs, ferns, seeds and reeds. When these plants were fallen and died, peat can easily be developed because these water-logged

condition is preferable the rate of peat accumulation to that of the decomposition. Since, these peats are normally flooded mainly by the rain water and no longer enriched by influx of plant nutrient from outside, they are so poor in nutrient and contain high fiber contents.

In 1968, all of these peat swamps remained undisturbed. Most of them had the organic layer of thicker than 1 m and has been recognized as the Narathiwat series. According to the need of the land for cultivation, some main swamps have been developed. In 1975, the irrigation canals were constructed to evacuate the water from the swamps.

Immediately these swamps started to develop, changes have been occurred to some extent, resulting in various adverse effects on soil conditions. Firstly, burning of the peat as a consequence of forest clearance, causes great subsidence of the peat layer. When the peat layer became thinner, the underlying mineral soils have become acidified. Therefore, in many places, these peat soils have converted to typical acid sulfate soils. Moreover, this has also resulted in drainage waters becoming extremely acid in many areas.

### 2.1.2 Classification of Peat

Peat is in histosols order. It is classified as soil organic matter in soil taxonomy system. According to the decomposition degree of peat, peat is divided into 3 suborders (13);

(1) Fibrists : this is the least degree of decomposition, high fiber content and low bulk density.

(2) Hemists : this is medium degree of decomposition. Its bulk density is about 0.07-0.18 and one third fiber content.

(3) Saprists : this is the most degree of decomposition. Fiber content is less than one third and its bulk density is equal or more than 0.3.

Vijarnsorn (14) reported that peat in Narathiwat province is divided to 2 soil series, Narathiwat (Nw) and Kab-Daeng (Kd). Nw decomposed less than Kd and thicker than Kd. Nw may be deep to 130 cm while depth of Kd is less than 130 cm.

### 2.1.3 Chemical Properties and Composition of Peat

There have been various evidences indicate

that peat composed of the following component (15):

(1) Organic matter in an organized state of preservation and, therefore, identifiable.

(2) Organic matter which has undergone considerable breakdown but in which cell structure is still visible.

(3) Organic matter which has been degraded below the cellular level, composing what might be termed "humus" and often forming a peat matrix.

(4) Inorganic matter derived either from dust or inwash, or from the cells of some plants.

The proportions of each of these components will vary from one peat sample to another depending on the nature of the peat-forming material and the rate of the decomposition. Thus, peat is a chemically heterogeneous and very complex material. There has been only few works done an investigation of peat composition in Thailand.

Polak (16) has studied components of peat and concluded that peat component in tropical zone was significantly different from peat in temperate zone, except high percent of lignin was found in tropical zone. However, peat component in Narathiwat province by Tongcumpou (5) showed that percent of lignin in peat from Narathiwat province is slightly higher than in

the tropical zone. According to work done by Jarearnpong (17) and Vijarnsorn (18) on characteristics of peat in Narathiwat to indicate the potential of peatland for agriculture. The results showed that peatland in Narathiwat was rather unsuitable for agriculture, because of its low fertility, especially on important nutrient such as phosphorus (P) and potassium (K).

Bunnumma (19) studied on humic acid extraction from peat and reported that the quantity of humic acid of Narathiwat peat was between 16.19-44.65%, humic acid isolated from peat in Bacho swamp (28.38%) is higher than Todaeng swamp (27.85%), development zone (30.67%) is higher than conservation zone (25.04%) and Nw soil serie (28.90%) is higher than Kd soil serie (25.52%). For the properties of humic acid, CEC of humic acid isolated from Bacho swamp is between 173.06-329.43 meq/100 g and Todaeng swamp is between 162.30-288.31 meq/100 g.

## 2.2 Utilization of Peat as Cation Exchanger

Peat is contained of lignin and cellulose as major constituents. The chemical composition and particulate nature of peat make it an effective

adsorbent and filtration medium in the purification of waste water. Lignin is one of the constituents which bear polar functional groups, such as alcohols, aldehydes, ketones, acid, phenolic hydroxides and ether (20). These polar functional groups can be involved in chemical bonding. According to the character of these groups, peat can catch many kinds of metal.

#### 2.2.1 Exchangeable Capacity of Peat

Peat in its nature form has cation exchange properties (21). However, raw peat is very impervious to flow and can be used in a flow system only after being dried. According to the consideration of material which has exchangeable capacity, the total exchange capacity of the material is one of the most important characteristics of ion exchange resins. The ionic sites per unit volume, or per unit weight of the resin is a measure of the number of available or potentially available.

There are studies on utilized peat as cation exchanger or adsorbent both in type of batch and column operation. Many treatment were used for peat activating in the term of exchangeable capacity.

It has shown that peat exhibits enhanced cation exchange capacity after treatment with concentrated sulfuric acid (22, 23, 24, 25, 26).

Smith and his colleagues (24) studied on cation exchange capacity of peat after treatment with concentrated sulfuric acid on column system. They found that the best condition was at 200° c. When it was treated with 15 ml of concentrated sulfuric per 1.2 gram of dried peat its capacity was 2.82 meq/g for copper ion.

The study on Narathiwat's peat utilization as cation exchanger of Tongcumpou (6) was designed to determine exchange capacity of peat in column system using Rohm and Hass's Method. Both treated and untreated peat samples was determined and the results, as presented in Table 1, showed that the exchange capacity of the treated samples was slightly decreased. The highest capacity appeared to be only 0.46 meq/g. While the synthetic resins are about 2-8 meq/g depending on type of resins.

Table 1 Column exchange capacity of Narathiwat's peat

Capacity Untreat	Treatment								
	1 N H <sub>2</sub> SO <sub>4</sub>			6 N H <sub>2</sub> SO <sub>4</sub>			18 N H <sub>2</sub> SO <sub>4</sub>		
	1 hr	2 hr	3 hr	1 hr	2 hr	3 hr	1 hr	2 hr	3 hr
meq/100g 42.80	40.22	33.79	37.34	46.34	32.93	37.26	35.25	33.25	33.85
Mol/kg 428	402	338	373	463	329	373	355	333	339

Source : Tongcumpou C. The study on peat utilization as cation exchanger, 1987.

### 2.2.2 Heavy Metal Removal

Numerous studies have been conducted on the development of utilized peat for metal trapping (20, 24, 27, 28). Bunzl (29, 30, 31) had studied on kinetics of ion exchange during continuous addition of Pb<sup>2+</sup> ions to humic acid and peat, investigating exchange

process in batch experiment, in which the exchangeable ions were added continuously as a function of time to a well stirred dilute aqueous suspension of the ion-exchange particles. He reported that the humic substances exhibit the same kinetic as the ion exchange resin. In 1976, Bunzl and coworkers (31) had studied on the adsorption and desorption rates of  $Pb^{2+}$ ,  $Cu^{2+}$ ,  $Cd^{2+}$ ,  $Zn^{2+}$  and  $Ca^{2+}$  by peat. The results on distribution coefficients showed that the selective order for the metal adsorption by peat is  $Pb^{2+} > Cu^{2+} > Cd^{2+} = Zn^{2+} > Ca^{2+}$  in the pH range from 3.5 to 4.5.

According to work done by Greenland (32) and Stevenson (33) on the capacity of peat and humic acid in different conditions, it was also found that the order of selectivity adsorption was  $Cu^{2+} > Cd^{2+} > Zn^{2+}$  respectively.

Similar results of adsorption capacity in order of  $Cu^{2+}$ ,  $Cd^{2+}$  and  $Zn^{2+}$  on Narathiwat's peat have also been demonstrated by Tongcumpou (6).

### 2.3 Related Theories of Adsorption

Knowledge of ion exchange technology has been developed for along time. This is evident as many

researchs have been conducted (24, 26). Peat is interesting material for using as cation exchanger. However, to study its ion exchange capacity it is necessary to know about many related theories. Adams and Bohart's equation and Freundlich's equation are some guidance for this study. The formation of these two equations will be presented later.

### 2.3.1 Elementary Aspects of Adsorption

Adsorption, as the term is used here, applies to the physical transfer of a solute in a gas or liquid to a solid surface where the solute is held as a result of intermolecular attraction with the solid molecules (34). Atoms and molecules are held together in a solid by cohesive forces that range from strong valence bonds to the relatively weak Van Der Waals forces of attraction. Molecules in the interior of a solid are completely surrounded, consequently their attractive forces are satisfied on all sides. The attractive forces do not cease abruptly at the surface. Instead they extend outward and can capture wandering fluid molecules—a phenomenon that is known as adsorption. The terms adsorbent and adsorbate describe the solid and its captured

molecules.

The procedure for determining the distribution between the quantity adsorbed and the concentration remaining in solution is as follows (35):

a) Different weighed amounts of adsorbent are added to separate flasks, all containing equal volumes of the solution being studied.

b) The contents of the flasks are stirred at uniform temperature until adsorption equilibrium is reached.

c) The adsorbent is separated from the system by filtration and the concentration remaining in the filtrate is measured.

The data are coded :

$C_0$  original concentration

$C$  concentration remaining in solution  
or final concentration

$C_0 - C$  amount adsorbed

$m$  weight of adsorbent

$x/m$  amount adsorbed per unit weight  
of adsorbent

Knowledge of the relationship between the amount of substance adsorbed and the concentration remaining unadsorbed is of practical utility. Many research have shown that the concentration on the

adsorbent is usually proportional to a power or a fractional power of the concentration that remains unadsorbed. Expressed mathematically :

$x/m$  is proportional to  $C^{1/n}$

This is converted to an equation by introducing a constant  $K$  which forms the classical Freundlich's equation.

$$x/m = KC^{1/n}$$

For data collected at identical temperature, an isotherm is formed when  $x/m$  is plotted against  $C$ . If the plotting is done on logarithmic paper, the isotherm will generally be a straight line over a wide range of concentrations.

The exponent  $1/n$  in the Freundlich's equation is of practical utility because it discloses the adsorption pattern when different quantities of adsorbate are removed from a solution. The concentration on the adsorbent ( $x/m$ ) is proportional to the square root of the concentration remaining in solution.

When an isotherm has a 45° angle slope (i.e.

$1/n$  equals 1), the rate of change in adsorption concentration is identical with that occurring in solution (Figure 1). When the isotherm slope is steeper than  $45^\circ$  (i.e.,  $1/n$  is larger than 1.0) changes in the adsorbed concentrations outweigh changes in the solution concentrations.

An isotherm can be viewed as a map of the way in which an adsorbable solute distributes itself between the adsorbent and the solvent. Isotherm can convey an overall picture of many data more clearly than could be deduced directly from numbers.

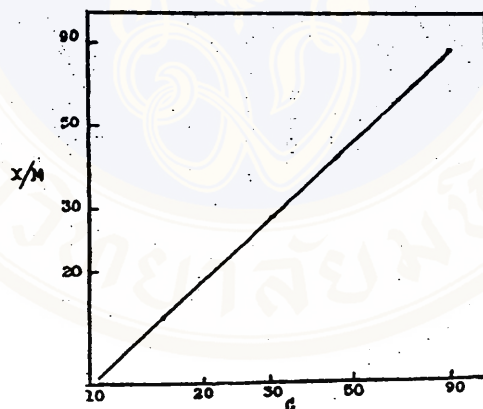


Figure 1 Adsorption isotherm ( $1/n$  equal to 1):

$C$ , concentration dye remaining in solution  
(mg/l)

$x/m$ , amount dye adsorbed (mg/g adsorbent)

Thus, when an isotherm is at a high level and has only a slight slope, as shown in Figure 2 (A), means that the adsorption is large throughout the entire range of concentration studied; conversely, a similar slope isotherm at a lower level, as shown in Figure 2 (B) indicates proportionately less adsorption. Next, consider an isotherm having a steep slope, as shown in Figure 3, this typifies an adsorption that is large at strong concentrations, but is much less at dilute concentrations.

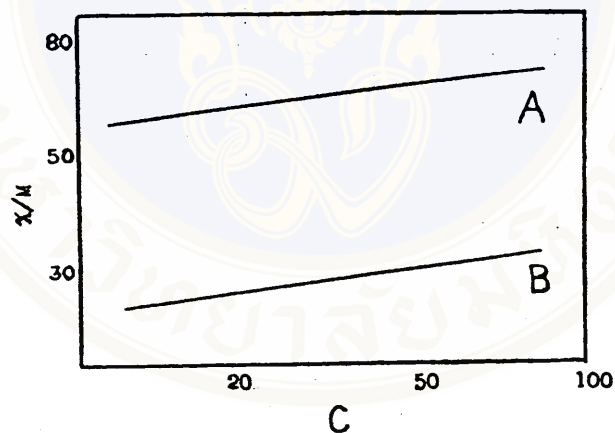


Figure 2 Adsorption isotherm (plotted logarithmically):

C, concentration dye remaining in solution  
(mg/l)

x/m, amount of dye adsorbed (mg/g adsorbent)

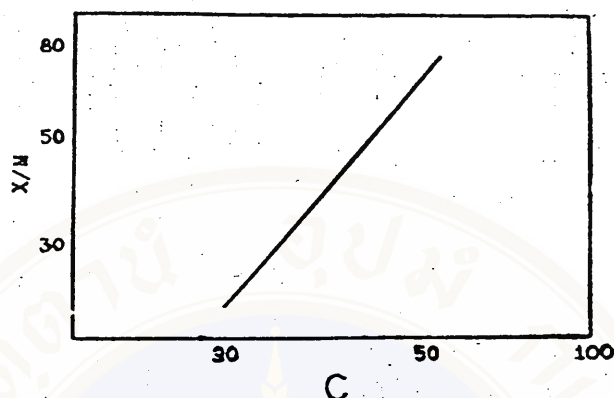


Figure 3 Adsorption isotherm (plotted logarithmically):

C, concentration of dye remaining in solution (mg/l)

x/m, amount of dye adsorbed (mg/g adsorbent)

The relative efficiency of different adsorbent is in direct proportion to x/m values measured at an identical concentration remaining in solution; and so, the isotherms afford a full view of the relative efficiency of adsorbents over the entire range of concentration studied. Thus, in Figure 4 adsorbents H has twice the relative efficiency of adsorbent J at a residual solution concentration of 10 ppm; at a concentration of 30 ppm both adsorbents are equal; and at a residual solution concentration of 100 ppm, adsorbent J has double the efficiency of adsorbent H.

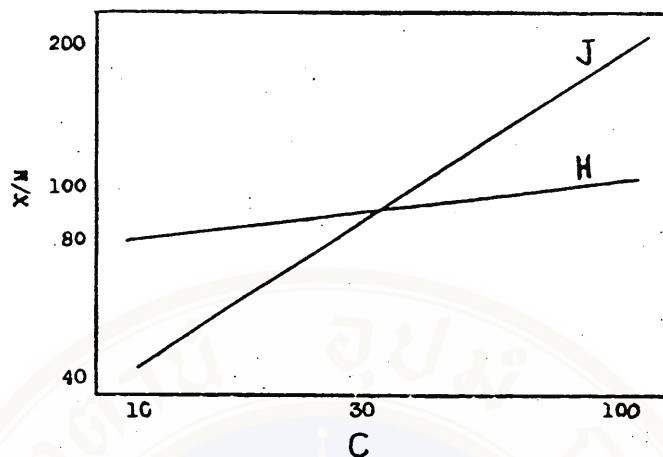


Figure 4 Adsorption isotherm (plotted logarithmically):  
 C, concentration in ppm remaining in solution  
 x/m, ppm adsorbed per gram of adsorbent

### 2.3.2 Elementary Aspects of Ion Exchange

Ion exchange can be thought of as a special case of adsorption, where a specially prepared ion exchange material serves as the adsorbent (34). The operating method for both cation and anion exchanger are currently done by 3 following methods :

(1) Batch operation : The ion exchanger is mixed in a vessel with the exchange solution and the solution is decanted when ionic equilibrium is reached.

(2) Column or Fixed bed operation : Column operation is similar to a series of batch equilibrium. The exhaustion step may be thought of as a series of equilibrium systems.

(3) Moving bed operation : In a moving bed operation, the resin passes through the column and the liquid being treated flows in the opposite direction.

Among the three methods, column operation is much favored. It is the most important and most frequently used laboratory technique. The ion exchanger is packed in a glass column and all necessary operations are carried out in this bed.

The rate of transfer in ion exchange is complicated by the complex of mechanism of the transfer process. A postulated mechanism of ion exchange consists of the following step (34):

(1) Diffusion of ions from the bulk liquid phase to the surface of the exchanger.

(2) Diffusion of the ions from the surface of the exchanger to the site of exchange.

(3) Exchange of the ions at the active site.

(4) Diffusion of the replaced ions from within the exchanger to its surface.

(5) Diffusion of the replaced ions from the exchanger surface to the bulk liquid.

When a solution of ions passes through a fixed bed of ion exchange material, the concentration of ions is reduced to zero as the solution contacts successive

portions of the bed (36). Attention is directed to Figure 5, which shows the location of a hypothetical concentration gradient in a fixed bed at different intervals of time. Such a gradient is located initially at the top of the bed and travels downward through the bed as the top layers of the exchange material became spent. At time  $t$ , the gradient is shown to be located entirely within the bed and none of the ionic species being removed escapes in the effluent. By time  $t_2$ , however, the gradient has receded to a point where the ions begin to appear in the effluent. At time  $t_3$ , the gradient has almost passed through the bed, and the concentration of ions in the effluent is close to that in the feed. Although the gradient, as shown in Figure 5, delineates a moving zone in which all the ions are removed from the solution, for convenience, an exchange zone is considered in which the concentration of the ions being removed is reduced from 95 to 5 percent of the feed concentration. For a given set of conditions, the height of the exchange zone as well as the rate at which it moves through the bed remain constant. Both height and rate will vary with feed rate, feed concentration, exchange capacity, and dimensions of the bed.

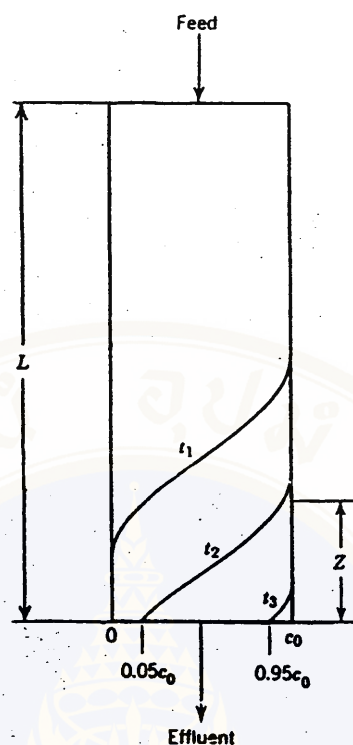


Figure 5 Location of a hypothetical solution concentration gradient in a fixed bed at different intervals of time.

The height of the exchange zone can be determined from an analysis of a breakthrough curve similar to those presented in Figure 6. Such curves, which can be constructed from data obtained in the laboratory, relate the effluent concentration of the ion being removed with the volume of effluent. In conformance with the definition given for the exchange zone, points of breakthrough and exhaustion are located at effluent ion concentrations equal to 5 and 95 percent of the feed ion concentration,  $C_0$ , respectively.

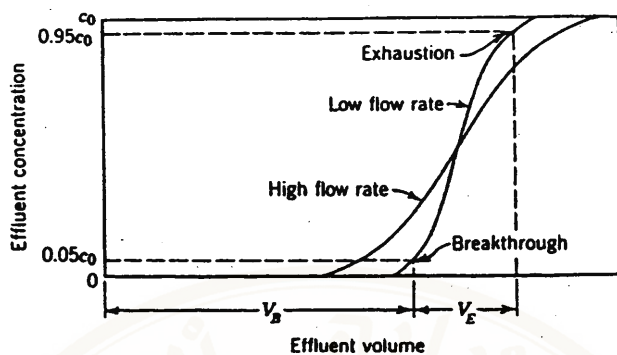


Figure 6 Typical breakthrough curves

### 2.3.3 Column Test

To search for adsorption isotherm is a batch operating method. That is only to determine whether adsorbent adsorption will accomplish effective purification. Equilibrium data for adsorption are usually presented in the form of adsorption isotherms. These data are necessary before the design equation can be applied. Although only adsorption isotherm data is not enough for the study of adsorption. According to the several interacting physical mechanisms involved in adsorption or ion exchange, and because such calculations are usually applied to a finite quantity of adsorbent in a cyclic operation, the design of fixed beds for ion exchange and adsorption can be involved procedure.

A schematic representation of a fixed-bed

adsorber is given in Figure 7 (34). While a solute-rich solution enters a fresh adsorbent bed, the solute in the solution begins adsorbing on the solid adsorbent. The rate at which adsorption occurs is influenced by one or more of several factors (34):

(1) Diffusion of solute from the following solution to the external surface of the solid particle.

(2) Diffusion of the solute into the gas-filled internal pores of the particle.

(3) Reaction at the solution-solid interface.

(4) Diffusion of the adsorbed solute within solvent phase.

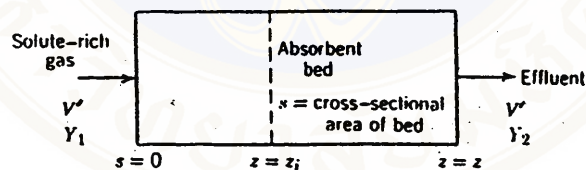


Figure 7 Adsorption in a fixed bed

The solid adsorbent will immediately adsorb solute until it is in equilibrium with the entering solution stream. Thereafter, the entering solution flows unchanged through this first increment, and onward to have its solute adsorbed in the next increment. This action continues until enough feed has

been introduced to saturate the entire bed to equilibrium with the solution, at which time the effluent solution instantaneously increases from zero concentration of solute to the concentration of the entering stream.

During the time the adsorption front is progressing through the bed, the unadsorbed component has been flowing through the remainder of the bed and out as the effluent. If the concentration of solute in the effluent is measured, it will be found to be zero until the time at which the bed becomes saturated; then it suddenly increases to the entering composition.

The time required to saturate the bed is a function of the adsorptive capacity of the bed, the flow rate, and the concentration of adsorbable constituent in the feed. Accordingly, a direct proportionality exists between the time required to saturate the bed and the cumulative effluent mass. With instantaneous adsorption, the front between the fully saturated bed and the fresh adsorbent moves through the bed until it reaches the effluent end, at which time a concentration change from zero to  $1/1$  occurs as the last increment of adsorbent becomes saturated. This sudden increase of solute concentration

in the effluent has been called breaking through the bed, leading to the designation breakthrough curves as the appropriate name of a plot of exit concentration as a function of time. Breakpoint is the point which the solution of effluent is maximum. Breakpoint time is the time during adsorption start to breakpoint. Breakpoint time is depend on :

- a) the height of adsorbent
- b) the particle of adsorbent
- c) flow rate of effluent
- d) the concentration of adsorbed solution

The continuous process of column test is according to Adams and Bohart's equation (37):

$$t = N_0/C_0 v \{ h - v/kN_0 [\ln (C_0/C_B - 1)] \} \dots(1)$$

$t$  = Breakpoint time or Service time (min)

$v$  = Velocity of effluent through adsorbent  
(superficial velocity) (cm/min)

$h$  = Height of adsorbent or depth of bed (cm)

$k$  = Rate of adsorption ( $\text{cm}^3/\text{mg}\cdot\text{min}$ )

$N_0$  = Adsorptive capacity ( $\text{mg}/\text{cm}^3$ )

$C_0$  = Influent concentration ( $\text{mg}/\text{cm}^3$ )

$C_B$  = Effluent concentration ( $\text{mg}/\text{cm}^3$ )

$$\text{From (1)} \quad t = N_0 h / C_0 v - 1 / C_0 k [\ln(C_0 / C_B - 1)] \quad \dots(2)$$

Compare with linear equation,

$$y = mx + c$$

$$\text{slope (m)} = N_0 / C_0 v \quad \dots(3)$$

$$\text{intercept (c)} = 1 / C_0 k [\ln(C_0 / C_B - 1)] \quad \dots(4)$$

The bed depth, which theoretically is just sufficient to prevent penetration of concentration in excess of  $C_B$  at zero time, is defined as the critical bed depth and is determined from (2) when  $t = 0$

$$h_0(\text{Critical bed depth}) = v / k N_0 [\ln(C_0 / C_B - 1)] \quad \dots(5)$$

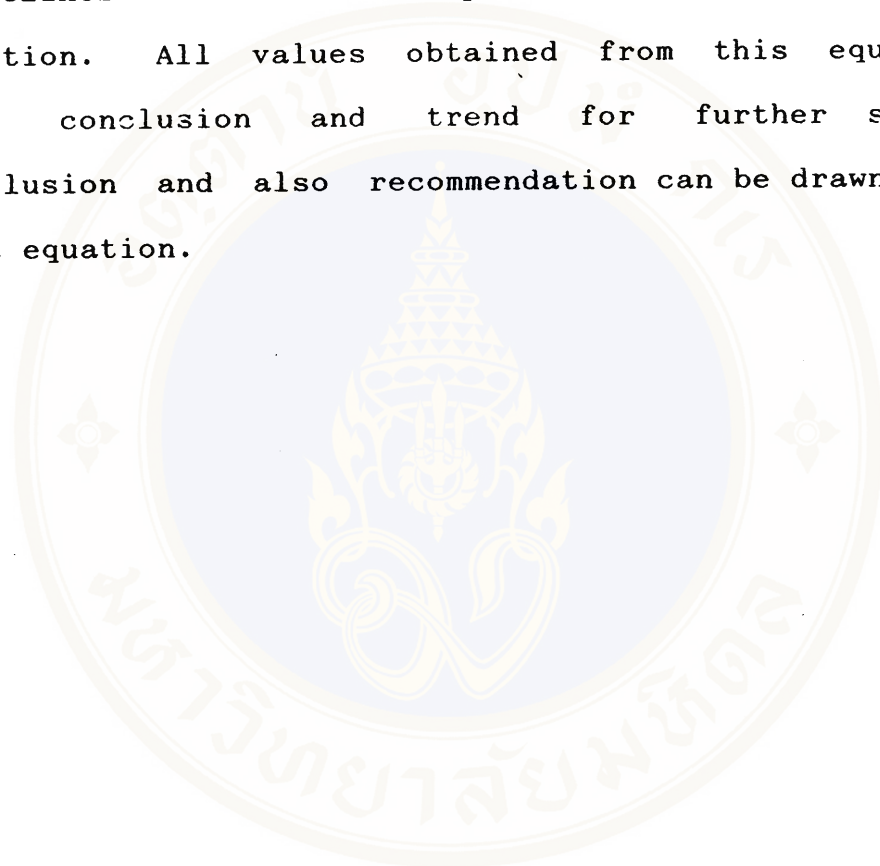
From (2), it can be shown that the adsorptive capacity  $N_0$  can be determined from a linear plot of  $t$  versus  $h$ . The rate of adsorption  $k$  is then calculated from the intercept of this plot.

#### 2.4 Summary

Peat information such as classification, characteristics and the study of peat in Narathiwat province told why an investigation of cation exchanger should be carried out. And it has showed

that peat is interesting material for being used as cation exchanger.

The related theories to this study are guidelines of this work especially Adams and Bohart's equation. All values obtained from this equation give conclusion and trend for further study. Conclusion and also recommendation can be drawn from this equation.





## CHAPTER III

### RESEARCH METHODOLOGY

#### 3.1 Materials

##### 3.1.1 Peat Samples

Peat samples collected from development and conservation zone of Bacho and Todaeng swamps, were used. Only Narathiwat (Nw) and Kabdaeng (Kd) soil series according to unit number of 20-26 and 13, 15 respectively, were taken.

##### 3.1.2 Apparatus

- Certified test sieves size 0.50 - 1.00 mm (mesh no.16-30)
- Test sieve shaker Model Octagon 200
- Suction pump
- Atomic absorption spectrophotometer Model Hitachi 180-50
- Stop watch

##### 3.1.3 Chemical Reagents

- 4 % Hydrochloric acid

- 50 ppm Copper sulfate penta hydrate  
( $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ )
- 50 ppm Tri-Cadmium sulfate octa hydrate  
( $3\text{CdSO}_4 \cdot 8\text{H}_2\text{O}$ )
- Standard Cd and Cu solution for AA. spectro.
- Methyl orange indicator

Note : All chemicals were analytical grade and preparing reagents were in Appendix B

#### 3.1.4 Glass-ware

- Glass column 1.8 cm I.D. 30 cm height
- Beaker 150, 250, 1,000 ml
- Buchner funnel
- Cylinder 10, 50, 100 ml
- Glass stirror
- Sample bottle
- Volumetric flask 10, 25, 50, 100, 1,000 ml

### 3.2 Experimental Procedure

#### 3.2.1 Peat Sampling

Peat samples from conservation and development zone in Bacho and Todaeng swamp were collected on

soil series. The overlay mapping technique topography, soil map of geography (1 : 50,000) and landuse map of peat in Narathiwat province (1 : 50,000) was used, and then sampling sites were selected using simple random sampling technique, considering of zoning area and landuse type. All the peat samples were obtained as the following criterias :

(1) The accessible sampling sites were distributed cover most of the development and conservation zone of both swamps.

(2) The areable peatland for peat sampling were Narathiwat (Nw) and Kabdaeng (Kd) soil series.

(3) Within 10 km<sup>2</sup>, at least one peat sample was collected for each sampling site.

### 3.2.2 Peat Preparation

Before experiment peat was prepared as followed:

(1) Raw peat is spread, leave it for open air-dried over 1 day and then further dried to reduce remaining moisture in the room at the temperature of 45-50°c using electric bulk as the heat source.

(2) Ground sample 1-2 min using high speed

blender and then sieved with test sieve shakers to 0.50-1.00 mm particle size.

### 3.2.3 Adsorption Isotherm Experiment

The prepared sample with particle size of 0.50-1.00 mm was divided to individual samples and mixed with heavy metal solution (Cd, Cu) for the time interval selected. The method followed by laboratory evaluation of adsorption; weighted 1, 5 and 10 g peat samples (accurately) in beaker then poured cadmium solution (50 ppm) 25 cm<sup>3</sup> in each beaker, stirred mixture in each beaker for 5 minutes and stand for one hour. After filtration the concentration of cadmium remain in filtrate was measured by Atomic Absorption Spectrophotometer. These data were, then, plotted in accordance with the Freundlich isotherm to determine the adsorption characteristics. From the curve obtained peat sample with high adsorptive capability. Instead, copper solution was conducted using the same procedure.

### 3.2.4 Column Test Experiment

The selected peat samples with high adsorption property have been chosen, and then mixed

together. A portion of selected peat was mixed with deionized water in beaker and then poured this mixture into the glass column (1.8 cm I.D., 30 cm height) which glass wool was cushioned in the bottom, and then glass wool was covered above. The height of peat sample and flow rate of solution applied according to the Table 2. The column treatment with 4 % HCl were conducted and then washed column with deionized water till the effluent is normal (checked the effluent by Methyl orange indicator). Let cadmium solution throughout the column and collected the sample of effluent from the column every 5 minutes until the concentration of effluent was  $3 \times 10^{-5}$  mg/cm<sup>3</sup> (or collected for 1-2 hrs/1 column) and the concentration of effluent was measured using AA. spectrophotometer. Then break point has been considered the time from starting run column when the concentration of effluent was  $3 \times 10^{-5}$  mg/cm<sup>3</sup>. All the results obtained were plotted for service time versus bed-height and  $N_0$ ,  $h_0$ ,  $k$  versus velocity, and then used for further calculation. The same procedure was applied for copper solution but the break point was the point which concentration of effluent was 0.001 mg/cm<sup>3</sup>.

Table 2 Bed-height of peat column, flow rate of cadmium and copper solution for column test

Cadmium Solution		Copper Solution	
Flow Rate (cm <sup>3</sup> /min)	Bed-height of peat Column (cm)	Flow Rate (cm <sup>3</sup> /min)	Bed-height of peat Column (cm)
1.3	3	2.5	4
	4		5
	5		6
	6		6.5
	7		7
2.0	4	3.0	4
	6		6
	7.5		7
	8.5		8.5
	11		9.5
3.1	5	4.5	5
	6		6
	7		7
	7.5		8
	10		9

### 3.2.5 Application of Adams and Bohart's Equation

In order to explain the apparent from column test experiment Adams and Bohart's equation (see section 2.3.3) is being applied as follow :

#### 3.2.5.1 Column Efficiency Calculation

(1) Column efficiency calculated from bed-height :

$$\text{efficiency} = \frac{h - h_0}{h} \quad \dots(6)$$

$$\% \text{ efficiency} = \frac{h - h_0}{h} \times 100 \quad \dots(7)$$

(2) Column efficiency calculated from adsorptive capacity :

$$\text{From (2)} \quad t \times C_0 \times v = N_0 h - v/k[\ln(C_0/C_B - 1)]$$

$$\begin{aligned} \text{efficiency} &= \frac{t \times C_0 \times v}{N_0 h} \\ &= \frac{N_0 h - v/k[\ln(C_0/C_B - 1)]}{N_0 h} \quad \dots(8) \end{aligned}$$

$$\% \text{ efficiency} = \frac{N_0 h - v/k[\ln(C_0/C_B - 1)]}{N_0 h} \times 100 \quad \dots(9)$$

$$\text{From (5)} \quad h_0 = v/kN_0[\ln(C_0/C_B - 1)]$$

$$\begin{aligned} \text{capacity loss} &= N_o h_o \\ &= v/k[\ln(C_o/C_B - 1)] \quad \dots(10) \end{aligned}$$

replace (10) to (8)

$$\begin{aligned} \text{efficiency} &= \frac{N_o h - N_o h_o}{N_o h} \\ &= \frac{N_o (h - h_o)}{N_o h} \\ \text{efficiency} &= \frac{h - h_o}{h} \quad \dots(11) \end{aligned}$$

$$\% \text{ efficiency} = \frac{h - h_o}{h} \times 100 \quad \dots(12)$$

It can be seen that column efficiency from (7) is equal to (12) as the value of  $N_o$ ,  $h_o$  and  $k$  have been derived from the same value of velocity. All these values will be used as a factor of further study for enlarged column.

However, in order to compare efficiency among columns, the same velocity value must be in consideration. In case of comparing the column efficiency at a different velocity, the equation (13) which is derived from (2) should be used for confirmation. Equation (13) is :

$$t \times v = N_0 h / C_0 - v / C_0 k [\ln(C_0 / C_B - 1)] \dots (13)$$

From (13), the column efficiency can be observed from the quantity of treated solution volume ( $t \times v$ ).



## CHAPTER IV

### RESULTS AND DISCUSSION

In this chapter the results of research findings are presented. Background data and calculations necessary for clarification are shown in the Appendix.

#### 4.1 Adsorption Isotherm

Adsorption isotherm is a batch test which is very useful for finding adsorption capability of peat and also to use as guidance to see if the particular peat sample can be used as adsorbent.

In order to evaluate the adsorption feasibility, a study under laboratory conditions was conducted. Two kinds of solutions, cadmium and copper, with concentration of 50 ppm have been tested with up to 9 selected peat samples. The peat samples used as adsorbent are varied with the weight of 1, 5 and 10 g. Only 25 ml of solution is taken for each experiment and then the concentration of the remaining metal in solution, the adsorbed metal were analysed and recorded as presented in Table 3 and Table 4.

From Table 3, all datas of cadmium solution experimental are plotted to show adsorption characteristics of each sample showing the ordinate

as the ratio of the adsorbed cadmium and weight of peat ( $x/m$ ) and the abscissa as the concentration of the remaining cadmium in solution (final concentration of cadmium). These resulting lines, as present in Figure 8 (a), are in accordance with the isotherm calculated by Freundlich equation (see section 2.3.1). The slope of isotherm line will present the adsorption capability of each peat sample. The steeper of line is showed the more of adsorbed cadmium is appeared. However, from this experiment, the minimum remaining concentration (1-15 ppm) of the four steepest lines are higher than the required concentration that being used as industrial waste water standard (0.03 ppm). Therefore, all these four samples (Kd 13, Kd 15, Nw 22, Nw 25) are useless to be considered as the selected representative samples for further analyses. Consequently, 5 samples (Nw 20, Nw 21, Nw 23, Nw 24, Nw 26) with the potential minimum concentration of lower than 0.01 ppm, as shown in Figure 8(a), are in consideration. And only two representative samples were selected (Nw 21, Nw23) for column test as its coverage adsorption capability value and being in consistence with those results presented by copper solution experiment.

The results from copper solution experiment

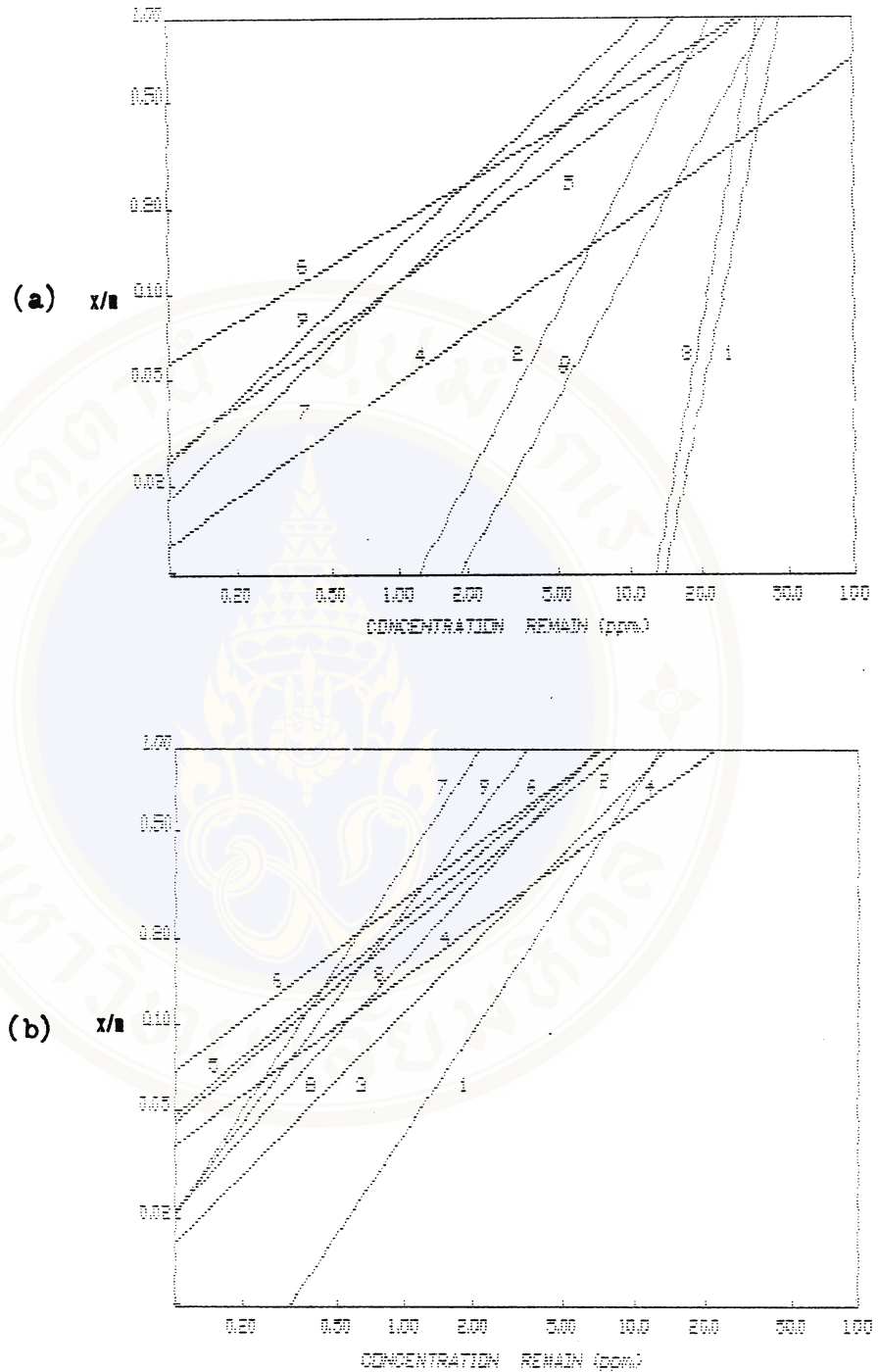


Figure 8 Adsorption isotherm of peat using (a)cadmium solution and (b)copper solution

Source : Table 3, 4

Note : (1) Kd13, (2) Kd15, (3) Nw20, (4) Nw21, (5) Nw22  
(6) Nw23, (7) Nw24, (8) Nw25, (9) Nw26

are presented in Table 4 and Figure 8(b). According to the same considerateness of cadmium experiment and with the industrial waste water standard of copper (1 ppm), the two representative samples (Nw 21 and Nw 23) for column test which are identical sample as cadmium solution experiment, are selected.

As aforementioned, it can be concluded that peat is capable for using as cation exchanger, as every sample has considerably showed its adsorption capability. However, under industrial waste water standard constraint, only 2 representative samples are reasonably selected.

#### 4.2 Column Test

In order to investigate if selected peat can be operated in larger column, the column test must be performed as the continuous column in which the service time (breakpoint time) will be obtained. For this experiment, Nw 21 and Nw 23 were mixed, and the two solutions of cadmium and copper have been applied on a glass column with  $\phi$  1.8 x 30 cm. The collected effluents have been analysed using Atomic Absorption Spectrophotometer (AA.), then were recorded and calculated using Adams and Bohart's

applied equation in order to obtain  $N_0$ ,  $h_0$ ,  $k$  that would be used for column efficiency calculation and column enlargement.

#### 4.2.1 Cadmium Solution

The condition used in this experiment are shown in Table 2 (Chapt.3). The results from this experiment are presented in Table 5 in which the service times are obtained and then are plotted, as presented in Figure 9(a), with the ordinate being the breakpoint time and the abscissa being the height of peat column. As we can see that the relationships of bed-height and service times are linear and being in accordance with a surface-reaction-rate theory, and Adams and Bohart's equation (see section 2.3.3). Adsorptive capacity ( $N_0$ ) and rate of adsorption ( $k$ ) are then calculated from slope and intercept respectively. The critical bed depth ( $h_0$ ) can also be calculated from equation as presented in section 2.3.3. These data are then plotted, as shown in Figure 10(a), with the ordinate being  $N_0$ ,  $h_0$ ,  $k$  and the abscissa being the cadmium solution velocity through the column. From this Figure, it can be seen that the values of adsorptive capacity, critical bed depth

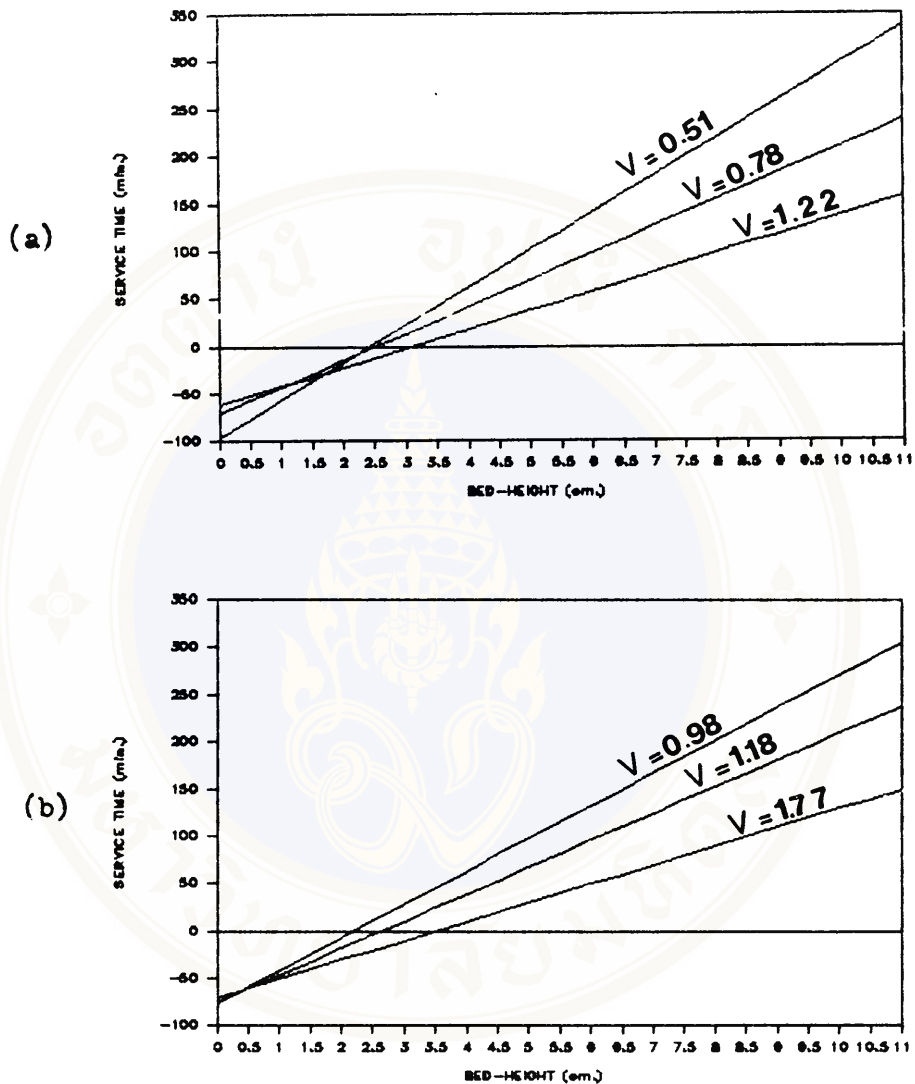


Figure 9 Service time and bed-height of peat column for (a) cadmium solution and (b) copper solution

Source : Table 5

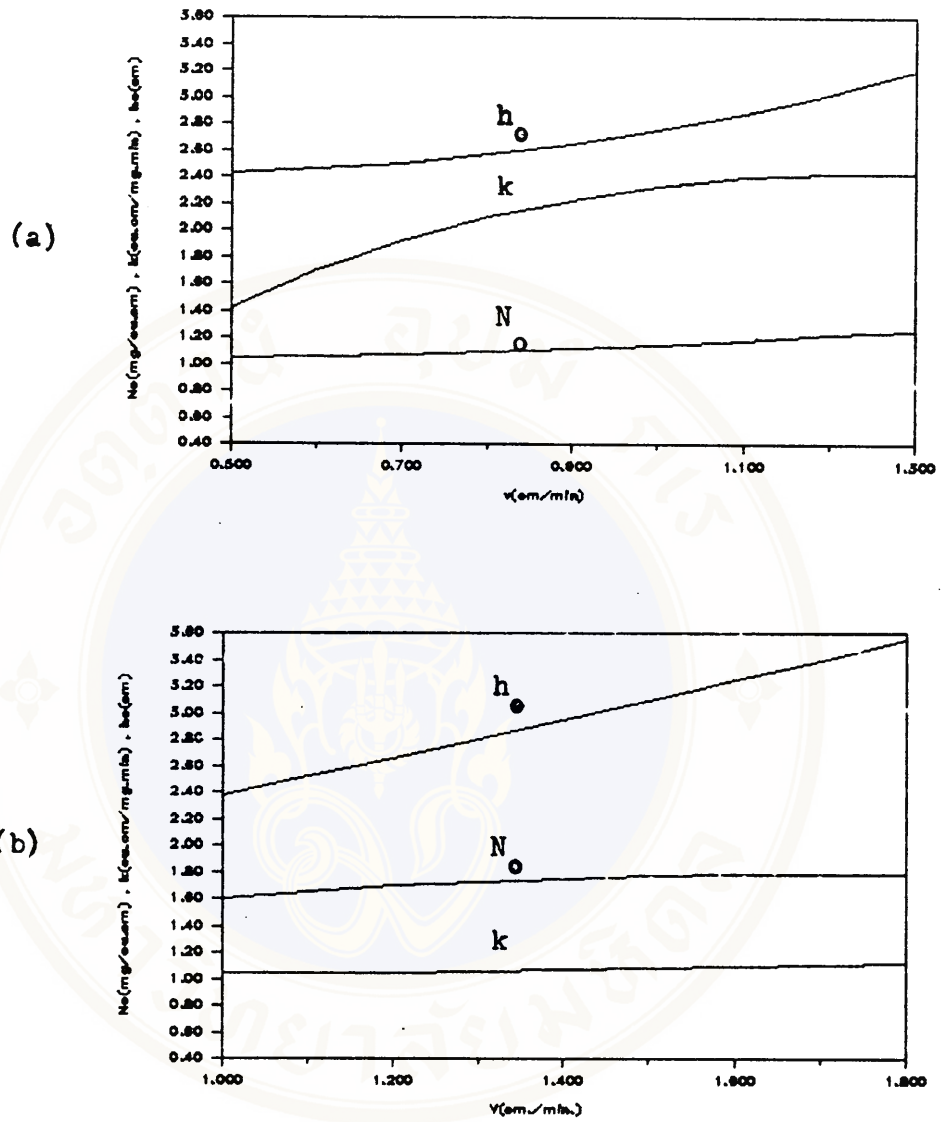


Figure 10  $N_0$ ,  $k$ ,  $h_0$  and  $v$  of (a)cadmium solution and (b)copper solution

Source : Table 5

and rate of adsorption will be determined by solution velocity. Increasing velocity tend to increase the critical bed depth and rate of adsorption but only slightly change appeared to be of the adsorptive capacity value. However, this relation can only be applied for a range of velocity of 0.51-1.22 cm/min, when the velocity have been changed then another relation of  $N_0$ ,  $h_0$ ,  $k$  will be occurred. It is also noted that the highest adsorptive capacity, rate of adsorption and critical bed depth are appeared at the highest velocity.

#### 4.2.2 Copper Solution

As the results presented in Figure 9(b), it can be seen that the relationships of bed-height and service time are also linear which is the same as cadmium solution. The calculated adsorptive capacity ( $N_0$ ), critical bed depth ( $h_0$ ) and rate of adsorption ( $k$ ) are presented in Figure 10(b). The results are also indicated that the solution velocities are the determinant of all adsorptive capacity values, critical bed depth and rate of adsorption. And the same relative pattern with cadmium solution has been shown at the applicable velocity range of 0.98-1.77 cm/min. The

highest adsorptive capacity, rate of adsorption, critical bed depth and solution velocity are also considerably noted.

As the mentioned above, the conclusion of column test can be drawn. It is shown that peat can be operated as continuous column, providing adsorptive capability ( $N_0$ ), rate of adsorption ( $k$ ) and critical bed depth ( $h_0$ ) needed for calculation of column efficiency and column enlargement.

#### 4.3 Column Efficiency

It has been shown that the highest adsorptive capacity, rate of adsorption and critical bed depth will be presented with the highest velocity (Figure 10). From this result, it is however questionable that whether the highest column efficiency will also be obtained, as the comparative efficiency must be performed within the same velocity.

As previously mentioned in Chapt. 3, column efficiency can be calculated from either adsorptive capacity value or bed-height using the applied Adams and Bohart's equation (see section 3.2.5).

#### 4.3.1 Cadmium Solution

Using adsorptive capacity calculation, as presented in Figure 11 the calculated column efficiency using different cadmium solution velocity ((a) 0.51, (b) 0.78, (c) 1.22 cm/min) showed that the value of total capacity, capacity loss and efficiency are slightly changed with the solution velocity. Comparing within the particular velocity the total capacity will be increased with bed-height while the capacity loss is constant and slightly increasing of efficiency is observed. It is noted that increasing solution velocity might not be profitable as a gradually decreasing of efficiency has been observed.

In case of using bed-height calculation, as shown in Figure 12(a), the results seem to indicate that the lower velocity will give rise to the higher column efficiency. But this comparison could not be possible as the aforementioned that any comparison must be performed within the same velocity. Therefore this result can only be shown that the variation of column efficiency are potentially dependent on bed-height.

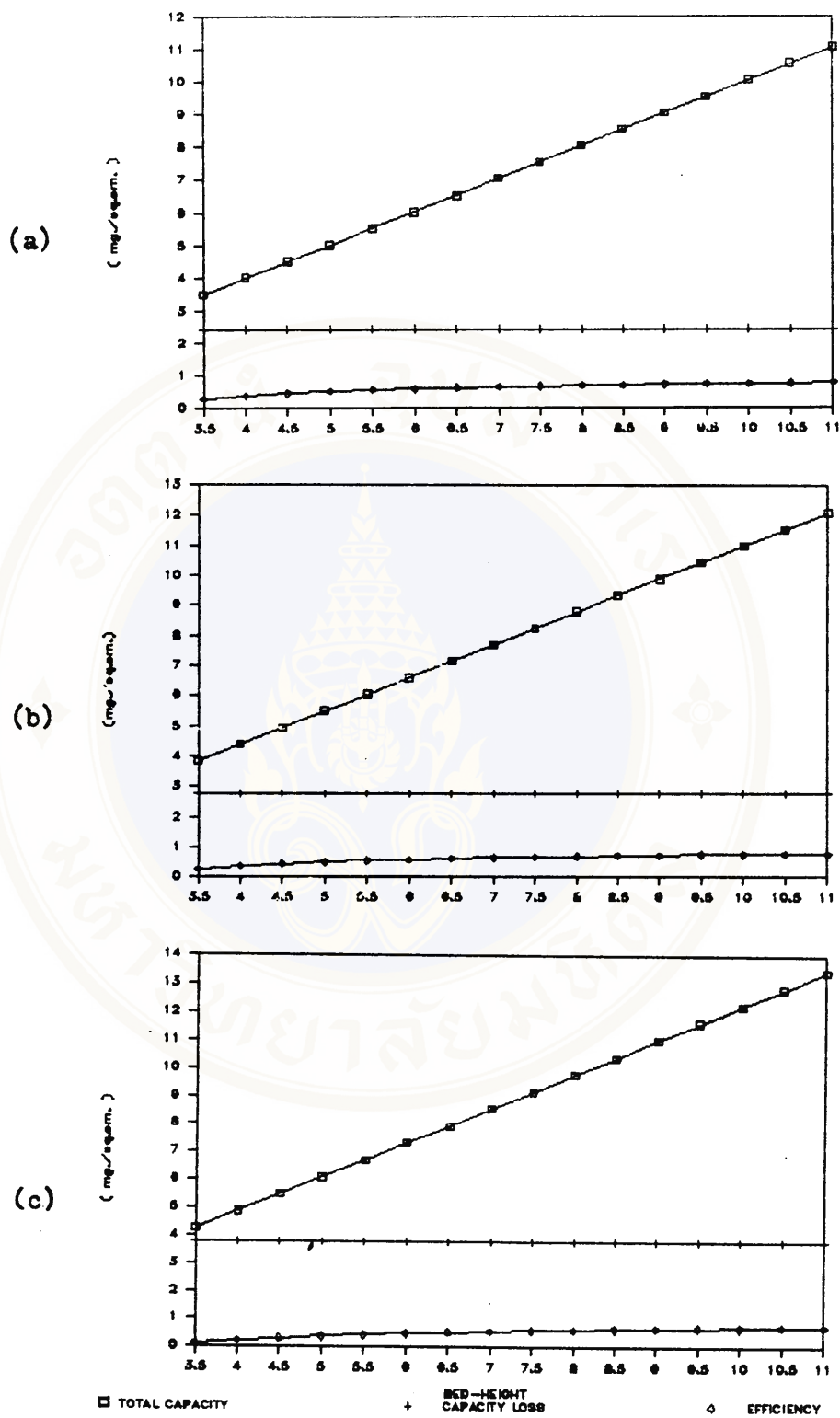


Figure 11 Calculated column efficiency using cadmium solution velocity of (a) 0.51 cm/min (b) 0.78 cm/min and (c) 1.22 cm/min

Source : Table 7, 8, 9

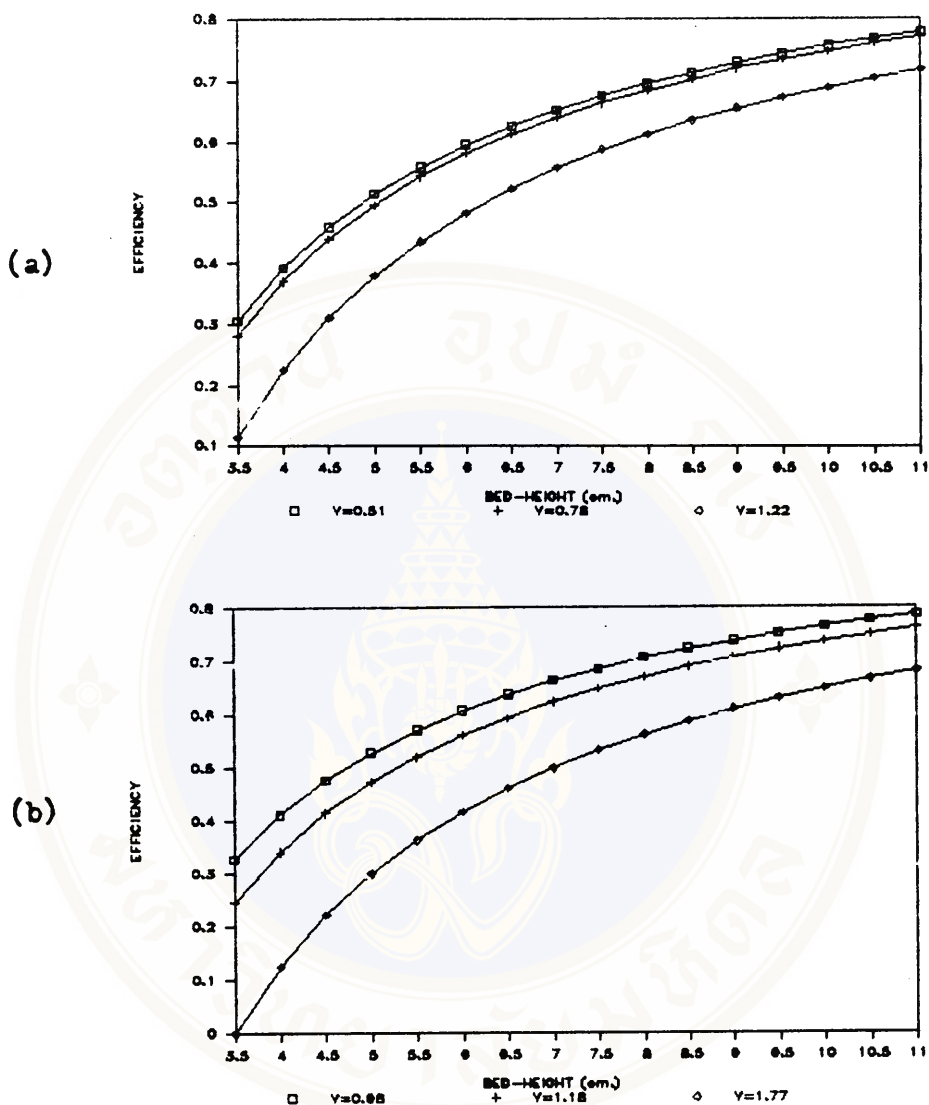


Figure 12 Column efficiency of peat using (a) cadmium solution and (b) copper solution calculated from bed-height

Source : Table 13, 14

#### 4.3.2 Copper Solution

As the results of calculated adsorptive capacity presented in Figure 13. It can be seen that the calculated column efficiency results using different copper solution velocity ((a)0.98, (b)1.18, (c)1.77 cm/min) are considerably the same as using cadmium solution. Increasing solution velocity might not be profitable as a slightly decreasing of column efficiency are also noted.

On account of bed-height calculation, as shown in Figure 12(b), the results are also consistent with the results obtained by cadmium solution. It is also observed that column efficiency can only be varied with bed-height. This result has confirmed that any efficiency must be compared within the same velocity.

#### 4.4 Treated Solution Volume

In order to compare column efficiency at a different velocity, the treated solution volume ( $t \times v$ ) which is calculated from equation (13) (see section 3.2.5) can be observed.

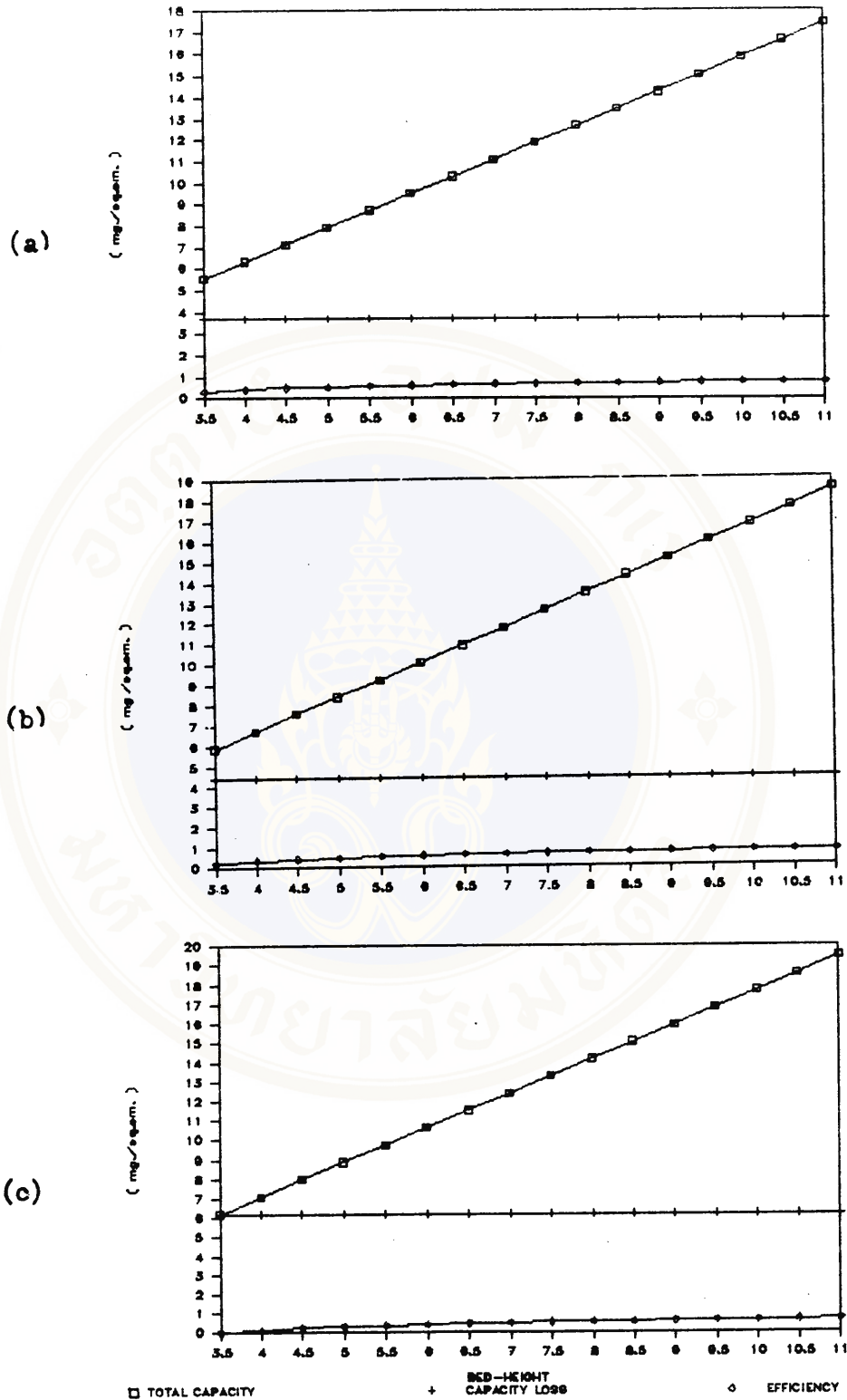


Figure 13 Calculated column efficiency using copper solution velocity of (a)0.98 cm/min (b) 1.18 cm/min and (c)1.77 cm/min

Source : Table 10, 11, 12

#### 4.4.1 Cadmium Solution

The calculated volume of treated cadmium solution are shown in Table 15. These data are then plotted, as shown in Figure 14(a), with the ordinate being  $t \times v$  and the abscissa being bed-height of peat. It can be seen that three crossed dots from these three lines of this graph are  $x_1$ ,  $x_2$  and  $x_3$  showing 3.468, 6.270 and 8.428 respectively. As we know before, we can compare column efficiency at a different velocity from the calculated treated solution volume. It concluded that the volume of treated cadmium solution at any range of bed-height are :

(1) at bed-height of lower 3.468, the volume of treated cadmium solution obtained using solution velocity of 0.51 cm/min, is higher than the velocity of 0.78 and 1.22 cm/min.

(2) at bed-height of 3.468, the volume of treated cadmium solution obtained using solution velocity of 0.51 cm/min, is equal to the velocity of 0.78 and higher than the velocity of 1.22 cm/min.

(3) at bed-height of 3.468 to 6.270, the volume of treated cadmium solution obtained using solution velocity of 0.78 cm/min, is higher than the

velocity of 0.51 and 1.22 cm/min.

(4) at bed-height of 6.270, the volume of treated cadmium solution obtained using solution velocity of 0.78 cm/min, is higher than the velocity of 0.51 cm/min and the volume of treated cadmium solution obtained using solution velocity of 0.51 cm/min is equal to the velocity of 0.78 cm/min.

(5) at bed-height of 6.270 to 8.428, the volume of treated cadmium solution obtained using solution velocity of 0.78 cm/min, is higher than the velocity 1.22 cm/min and 0.51 cm/min.

(6) at bed-height of 8.428, the volume of treated cadmium solution obtained using solution velocity of 0.78 cm/min, is equal to the velocity of 1.22 cm/min and the treated cadmium solution obtained using solution velocity of 1.22 cm/min is higher than the velocity of 0.51 cm/min.

(7) at bed-height of 8.428, the volume of treated cadmium solution obtained using solution velocity of 1.22 cm/min, is higher than the velocity of 0.78 and 0.51 cm/min.

It is noted that using cadmium solution at any solution velocity must also be considered at any range of bed-height of peat column. It is appeared that at low bed-height, the lower solution velocity

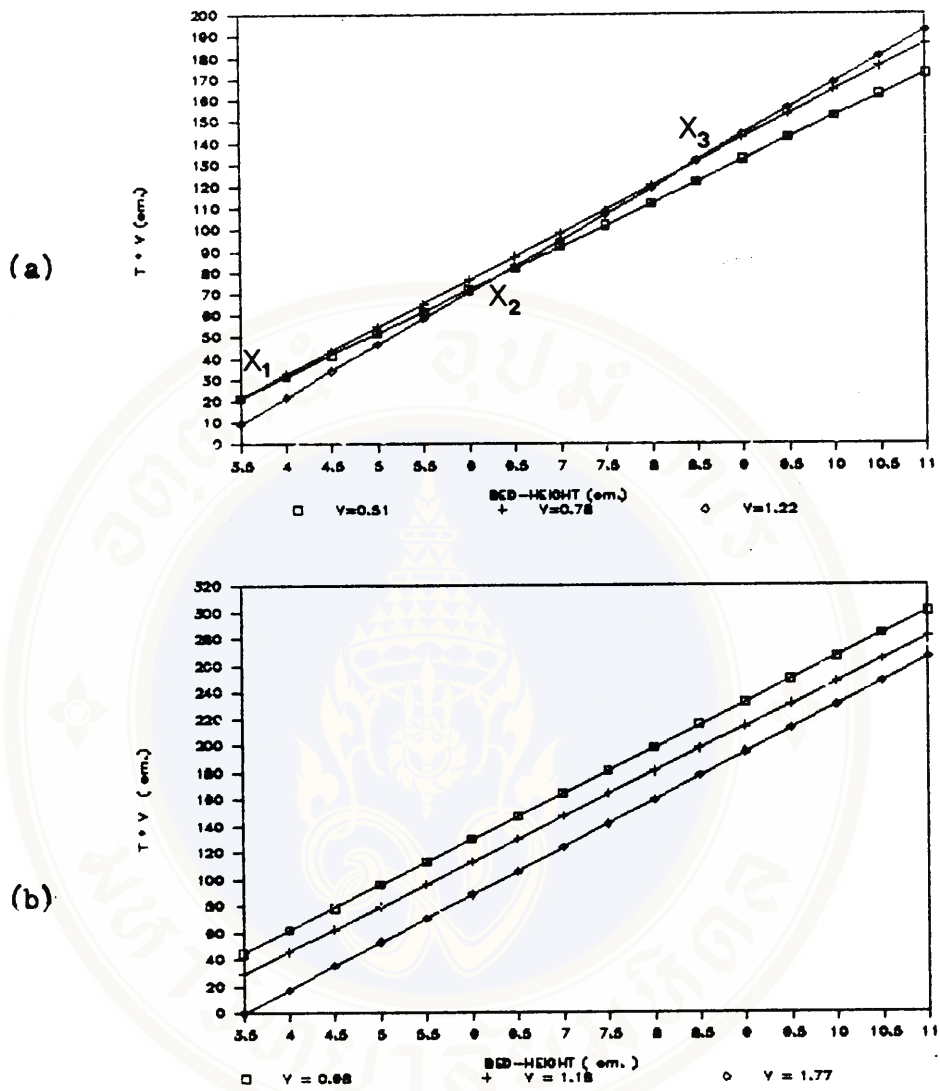


Figure 14 Treated volume of (a)cadmium solution and (b) copper solution

Source : Table 15, 16

will give rise to the high column efficiency. Then at high bed-height, high efficiency will be obtained when the high solution velocity is used.

#### 4.4.2 Copper Solution

As the result presented in Table 16 and Figure 14(b), the lowest velocity of 0.98 cm/min will give the most highest volume of treated copper solution at every bed-height of peat. It is noted that using copper solution the lowest velocity can give rise to the best column efficiency.

#### 4.5 Application of the Experimental Results

In order to see if the results obtained from column test experiment can be applied for column enlargement. The expected column size must be set up and chose the value of  $N_0$ ,  $h_0$ ,  $k$  and  $v$  from the column test experiment (Figure 10, Table 6). Then calculation for flow rate used in experiment and effluent ( $C_B$ ) obtained at various time using Adams and Bohart's equation was applied, as the results shown in Table 17, 18. These calculated results show that in case of cadmium solution, the service time to

meet the requirement of industrial waste water standard may be obtained at 138 min while only 130 min appeared to be of copper solution.

It is clearly shown that peat is capable to some extent for heavy metal removal. However, in practice it is rather inconvenient to use it as cation exchanger column as peat regeneration may be required at every 2 hours. Eventhough, increasing bed-height to increase column efficiency can be done but capacity loss due to critical bed depth and adsorptive capacity of peat must be taken for consideration. Therefore, the influence of physical factors that effecting peat column should be further investigated.

## CHAPTER V

### CONCLUSION AND RECOMMENDATION

#### 5.1 Conclusion

##### 5.1.1 The Capability of Peat as Cation Exchanger Column

Results from this work confirmed that peat are capable for being cation exchanger. Adsorption isotherm are shown that every samples of peat have adsorption capacity to some extent, depending on source and quality of peat. Nw soil serie with unit no. 21 and 23 are peat representatives as its coverage adsorption capability value.

From the study of peat in continuous column acquired the result which confirmed that peat can be used as cation exchanger column. This study proceeded to Adams and Bohart's (see section 2.3.3 and 3.2.5), which have developed a relationship base on a surface-reaction rate theory, that can be used to predict the performance of continuous column.

According to Adams and Bohart's equation (see section 2.3.3 and 3.2.5), the essential values acquired from experimental and calculation are obtained. They are adsorptive capacity ( $N_0$ ), rate of adsorption ( $k$ ) and critical bed depth ( $h_0$ ). The

conclusion drawn from these results showed that the capability of peat in heavy metal adsorption is dependent on  $N_0$  and  $k$ . However, the calculated column efficiency is determined by the critical bed depth ( $h_0$ ) used for any experiment.

#### 5.1.2 Enlarging Cation Exchanger Column

Adams and Bohart's equation is usually used to explain the relative behavior of the related variables obtaining from continuous column experiment. The obtaining values will be used as basic information for calculation of column enlargement.

#### 5.2 Recommendations

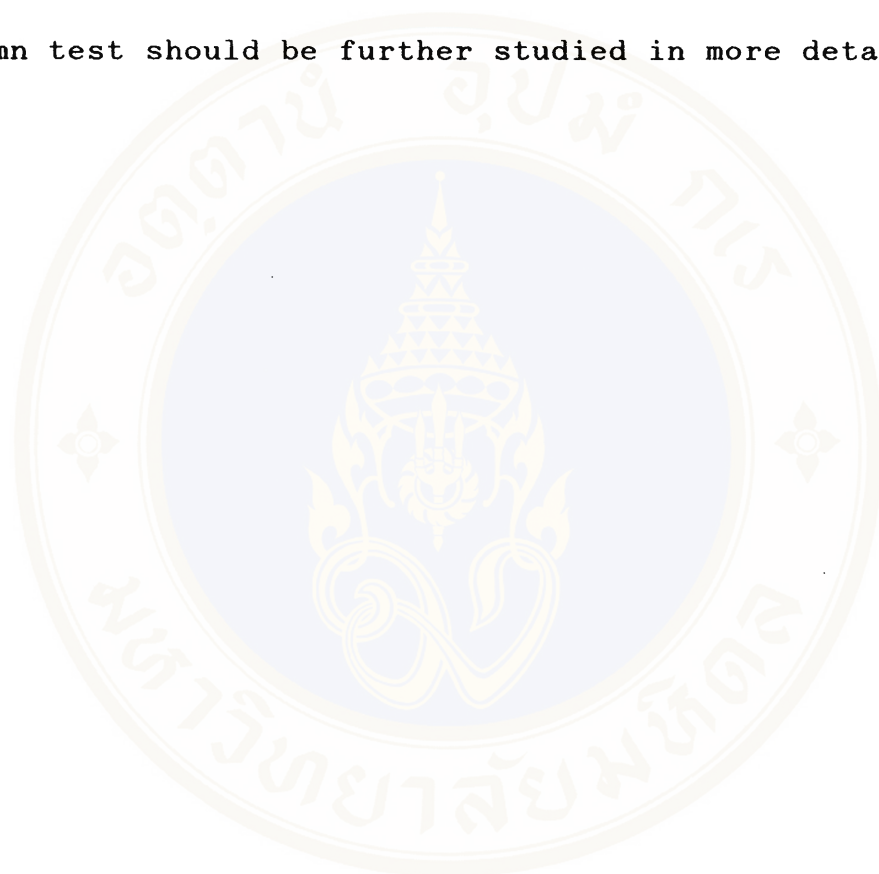
From this work the recommendations can be drawn as follows :

(1) In comparison of different heavy metals adsorption solution concentration, effluent concentration ( $C_B$ ) and bed-height of peat are recommended.

(2) In order to maximize adsorption capacity the application of multiple adsorption column is recommended.

(3) Peat regeneration should be further investigated in order to know the working life time of peat.

(4) The influence of related factors to pilot column test should be further studied in more details.



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## APPENDIX A

## TABLE OF RESULTS

Table 3 The remaining concentration in cadmium solution and  $x/m$  for isotherm

Peat Sample	Weight of Adsorbent (m) (gm)	Remaining Concentration in Solution (c) (ppm)	Adsorbed Cadmium (x) (mg)	$x/m$
Kd 13	1	35.50	0.36	0.36
	5	29.60	0.51	0.10
	10	23.20	0.67	0.07
Kd 15	1	19.60	0.76	0.76
	5	9.90	1.00	0.20
	10	5.70	1.11	0.11
Nw 20	1	31.45	0.46	0.46
	5	24.85	0.53	0.12
	10	20.60	0.74	0.07
Nw 21	1	34.05	0.40	0.40
	5	11.90	0.95	0.19
	10	4.20	1.14	0.11
Nw 22	1	20.40	0.74	0.74
	5	4.22	1.14	0.23
	10	1.20	1.22	0.12
Nw 23	1	19.65	0.76	0.76
	5	3.10	1.17	0.23
	10	0.40	1.24	0.12
Nw 24	1	14.10	0.90	0.90
	5	2.50	1.19	0.24
	10	1.00	1.22	0.12
Nw 25	1	27.10	0.57	0.57
	5	13.10	0.92	0.18
	10	8.55	1.04	0.10
Nw 26	1	10.45	0.99	0.99
	5	1.60	1.21	0.24
	10	0.80	1.23	0.12

Table 4 The remaining concentration in copper solution and x/m for isotherm

Peat Sample	Weight of Adsorbent (m) (gm)	Remaining Concentration in Solution (c) (ppm)	Adsorbed Cadmium (x) (mg)	x/m
Kd 13	1	13.10	0.92	0.92
	5	5.20	1.12	0.22
	10	2.40	1.19	0.12
Kd 15	1	9.11	1.02	1.02
	5	1.21	1.22	0.24
	10	0.41	1.24	0.12
Nw 20	1	13.00	0.92	0.92
	5	2.40	1.19	0.24
	10	1.16	1.22	0.12
Nw 21	1	17.47	0.81	0.81
	5	2.57	1.18	0.24
	10	0.74	1.23	0.12
Nw 22	1	7.52	1.06	1.06
	5	1.20	1.22	0.24
	10	0.42	1.24	0.12
Nw 23	1	8.07	1.05	1.05
	5	0.74	1.23	0.25
	10	0.30	1.24	0.12
Nw 24	1	2.40	1.19	1.19
	5	1.00	1.22	0.24
	10	0.41	1.24	0.12
Nw 25	1	7.58	1.06	1.06
	5	1.04	1.22	0.24
	10	0.66	1.23	0.12
Nw 26	1	4.02	1.15	1.15
	5	1.12	1.22	0.24
	10	0.50	1.24	0.12

Table 5 Service time of cadmium and copper solution from column test experiment

Cadmium Solution			Copper Solution		
Flow Rate (cm <sup>3</sup> /min)	Bed-height of peat Column (cm)	service time (min)	Flow Rate (cm <sup>3</sup> /min)	Bed-height of peat Column (cm)	service time (min)
1.3	3	22	2.5	4	55
	4	63		5	87
	5	102		6	125
	6	141		6.5	136
	7	180		7	152
2.0	4	42	3.0	4	38
	6	98		6	95
	7.5	140		7	117
	8.5	169		8.5	175
	11	240		9.5	195
3.1	5	39	4.5	5	31
	6	60		6	51
	7	80		7	68
	7.5	90		8	93
	10	140		9	112

Table 6 The calculated  $N_0$ ,  $k$  and  $h_0$ .

Cadmium Solution							Copper Solution						
Velocity (cm/min)	Slope	Intercept	$N_0$ (mg/cm <sup>3</sup> )	$k$ (cm <sup>3</sup> /mg.min)	$h_0$ (cm)	Velocity (cm/min)	Slope	Intercept	$N_0$ (mg/cm <sup>3</sup> )	$k$ (cm <sup>3</sup> /mg.min)	$h_0$		
0.51	39.5	96	1.007	1.545	2.430	0.98	32.3	76	1.583	1.024	2.352		
0.78	28.2	71	1.100	2.089	2.518	1.18	28.5	75	1.651	1.038	2.631		
1.22	20	62	1.220	2.393	3.100	1.77	20	70	1.770	1.112	3.500		

Table 7 The calculated column efficiency of 0.51 cm/min cadmium solution velocity

Bed-height of Column (cm)	Total Capacity (mg/cm <sup>2</sup> )	Capacity Loss (mg/cm <sup>2</sup> )	Column Efficiency
3.5	3.525	2.448	0.306
4	4.029	2.448	0.392
4.5	4.533	2.448	0.460
5	5.036	2.448	0.514
5.5	5.540	2.448	0.558
6	6.043	2.448	0.595
6.5	6.547	2.448	0.626
7	7.051	2.448	0.653
7.5	7.554	2.448	0.676
8	8.058	2.448	0.696
8.5	8.562	2.448	0.714
9	9.065	2.448	0.730
9.5	9.569	2.448	0.744
10	10.072	2.448	0.757
10.5	10.576	2.448	0.768
11	11.080	2.448	0.779

Table 8 The calculated column efficiency of 0.78 cm/min cadmium solution velocity

Bed-height of Peat Column (cm)	Total Capacity (ng/cm <sup>2</sup> )	Capacity Loss (ng/cm <sup>2</sup> )	Column Efficiency
3.5	3.843	2.769	0.281
4	4.399	2.769	0.371
4.5	4.949	2.769	0.440
5	5.499	2.769	0.496
5.5	6.049	2.769	0.542
6	6.599	2.769	0.580
6.5	7.149	2.769	0.613
7	7.699	2.769	0.640
7.5	8.248	2.769	0.664
8	8.798	2.769	0.685
8.5	9.348	2.769	0.704
9	9.898	2.769	0.720
9.5	10.448	2.769	0.735
10	10.998	2.769	0.748
10.5	11.548	2.769	0.760
11	12.098	2.769	0.771

Table 9 The calculated column efficiency of 1.22 cm/min cadmium solution velocity

Bed-height of Peat Column (cm)	Total Capacity (ng/cm <sup>2</sup> )	Capacity Loss (ng/cm <sup>2</sup> )	Column Efficiency
3.5	4.27	3.782	0.114
4	4.88	3.782	0.225
4.5	5.49	3.782	0.311
5	6.1	3.782	0.380
5.5	6.71	3.782	0.436
6	7.32	3.782	0.483
6.5	7.93	3.782	0.523
7	8.54	3.782	0.557
7.5	9.15	3.782	0.587
8	9.76	3.782	0.612
8.5	10.37	3.782	0.635
9	10.98	3.782	0.655
9.5	11.59	3.782	0.674
10	12.2	3.782	0.690
10.5	12.81	3.782	0.705
11	13.42	3.782	0.718

Table 10 The calculated column efficiency of 0.98 cm/min copper solution velocity

Bed-height of Peat Column (cm)	Total Capacity (ng/cm <sup>2</sup> )	Capacity Loss (ng/cm <sup>2</sup> )	Column Efficiency
3.5	5.539	3.724	0.328
4	6.331	3.724	0.412
4.5	7.122	3.724	0.477
5	7.913	3.724	0.529
5.5	8.705	3.724	0.572
6	9.496	3.724	0.608
6.5	10.287	3.724	0.638
7	11.079	3.724	0.664
7.5	11.870	3.724	0.686
8	12.662	3.724	0.706
8.5	13.453	3.724	0.723
9	14.244	3.724	0.738
9.5	15.036	3.724	0.752
10	15.827	3.724	0.765
10.5	16.618	3.724	0.776
11	17.410	3.724	0.786

Table 11 The calculated column efficiency of 1.18 cm/min copper solution velocity

Bed-height of Peat Column (cm)	Total Capacity (mg/cm <sup>2</sup> )	Capacity Loss (mg/cm <sup>2</sup> )	Column Efficiency
3.5	5.885	4.425	0.248
4	6.726	4.425	0.342
4.5	7.567	4.425	0.415
5	8.407	4.425	0.474
5.5	9.248	4.425	0.521
6	10.089	4.425	0.561
6.5	10.930	4.425	0.595
7	11.770	4.425	0.624
7.5	12.611	4.425	0.649
8	13.452	4.425	0.671
8.5	14.293	4.425	0.690
9	15.133	4.425	0.708
9.5	15.974	4.425	0.723
10	16.815	4.425	0.737
10.5	17.656	4.425	0.749
11	18.496	4.425	0.761

Table 12 The calculated column efficiency of 1.77 cm/min copper solution velocity

Bed-height of Peat Column (cm)	Total Capacity (ng/cm <sup>2</sup> )	Capacity Loss (ng/cm <sup>2</sup> )	Column Efficiency
3.5	6.195	6.195	0
4	7.080	6.195	0.125
4.5	7.965	6.195	0.222
5	8.850	6.195	0.300
5.5	9.735	6.195	0.364
6	10.620	6.195	0.417
6.5	11.505	6.195	0.461
7	12.390	6.195	0.500
7.5	13.275	6.195	0.533
8	14.160	6.195	0.562
8.5	15.045	6.195	0.588
9	15.930	6.195	0.611
9.5	16.815	6.195	0.631
10	17.700	6.195	0.650
10.5	18.585	6.195	0.667
11	19.470	6.195	0.682

Table 13 The calculated column efficiency from bed-height for cadmium

Bed-height of Peat Column (cm)	Column Efficiency		
	at $v = 0.51$ cm/min	at $v = 0.78$ cm/min	at $v = 1.22$ cm/min
3.5	0.306	0.281	0.114
4	0.392	0.370	0.225
4.5	0.460	0.440	0.311
5	0.514	0.496	0.380
5.5	0.558	0.542	0.436
6	0.595	0.580	0.493
6.5	0.626	0.612	0.523
7	0.653	0.640	0.557
7.5	0.676	0.664	0.587
8	0.696	0.685	0.612
8.5	0.714	0.704	0.635
9	0.730	0.720	0.656
9.5	0.744	0.735	0.674
10	0.757	0.748	0.690
10.5	0.768	0.760	0.705
11	0.779	0.771	0.718

Table 14 The calculated column efficiency from bed-height for copper

Bed-height of Peat Column (cm)	Column Efficiency		
	at $v = 0.98$ cm/min	at $v = 1.18$ cm/min	at $v = 1.77$ cm/min
4	0.412	0.342	0.125
4.5	0.477	0.415	0.222
5	0.529	0.474	0.300
5.5	0.572	0.521	0.364
6	0.608	0.561	0.417
6.5	0.638	0.595	0.461
7	0.664	0.624	0.500
7.5	0.686	0.649	0.533
8	0.706	0.671	0.562
8.5	0.723	0.690	0.588
9	0.739	0.708	0.611
9.5	0.752	0.723	0.631
10	0.765	0.737	0.650
10.5	0.776	0.749	0.667
11	0.786	0.761	0.682

Table 15 Treated solution volume for cadmium

Bed-height of Peat Column (cm)	t x v (cm)		
	at v = 0.51 cm/min	at v = 0.78 cm/min	at v = 1.22 cm/min
3.5	21.547	21.606	9.760
4	31.620	32.604	21.360
4.5	41.692	43.602	34.160
5	51.765	54.600	46.360
5.5	61.837	65.598	58.560
6	71.910	76.596	70.760
6.5	81.982	87.594	82.960
7	92.055	98.592	95.160
7.5	102.127	109.590	107.360
8	112.200	120.588	119.560
8.5	122.272	131.586	131.760
9	132.345	142.584	143.960
9.5	142.417	153.582	156.160
10	152.490	164.580	168.360
10.5	162.562	175.578	180.560
11	172.635	186.576	192.760

Table 16 Treated solution volume for copper

Bed-height of Peat Column (cm)	t x v (cm)		
	at v = 0.98 cm/min	at v = 1.18 cm/min	at v = 1.77 cm/min
4	61.936	46.020	17.7
4.5	78.988	62.835	35.4
5	96.040	79.650	53.1
5.5	113.092	96.465	70.8
6	130.144	113.280	88.5
6.5	147.196	130.095	106.2
7	164.248	146.910	123.9
7.5	181.300	163.725	141.6
8	198.352	180.540	159.3
8.5	215.404	197.355	177.0
9	232.456	214.170	194.7
9.5	249.508	230.985	212.4
10	266.560	247.800	230.1
10.5	283.612	264.615	247.8
11	300.664	281.430	265.5

Table 17 Calculated cadmium concentration effluent for column enlargement

Time (min)	Calculated cadmium concentration effluent ( $C_B$ ) ( $\text{mg}/\text{cm}^3$ )	standard industrial wastewater for cadmium solution ( $\text{mg}/\text{cm}^3$ )
20	$2.22 \times 10^{-11}$	
40	$2.43 \times 10^{-10}$	
60	$2.66 \times 10^{-9}$	
80	$2.91 \times 10^{-8}$	
100	$3.18 \times 10^{-7}$	
120	$3.48 \times 10^{-6}$	
138	$3.00 \times 10^{-5}$	$3.00 \times 10^{-5}$
150	$1.26 \times 10^{-4}$	
170	$1.34 \times 10^{-3}$	
190	$1.16 \times 10^{-2}$	
210	$3.84 \times 10^{-2}$	
230	$4.86 \times 10^{-2}$	
250	$4.99 \times 10^{-2}$	

Note :  $3.00 \times 10^{-5} \text{ mg}/\text{cm}^3 = 0.03 \text{ ppm}$

Conditions : column = 5 cm, h = 10 cm, cross-section area =  $19.63 \text{ cm}^2$ ,  
 flow rate =  $23.95 \text{ cm}^3/\text{min}$ , v = 1.22 cm/min,  $N_0 = 1.22 \text{ mg}/\text{cm}^3$ ,  
 k =  $2.392897 \text{ cm}^3/\text{mg}\cdot\text{min}$ ,  $h_0 = 3.1 \text{ cm}$

Table 18 Calculated copper concentration effluent for column enlargement

Time (min)	Calculated copper concentration effluent ( $C_b$ ) ( $\text{mg}/\text{cm}^3$ )	standard industrial wastewater for copper solution ( $\text{mg}/\text{cm}^3$ )
20	$2.25 \times 10^{-6}$	
40	$6.85 \times 10^{-6}$	
60	$2.08 \times 10^{-5}$	
80	$6.32 \times 10^{-5}$	
100	$1.92 \times 10^{-4}$	
120	$5.78 \times 10^{-4}$	
130	$1.00 \times 10^{-3}$	$1.00 \times 10^{-3}$
150	$2.92 \times 10^{-3}$	
170	$7.93 \times 10^{-3}$	
190	$1.82 \times 10^{-2}$	
210	$3.18 \times 10^{-2}$	
230	$4.20 \times 10^{-2}$	
250	$4.71 \times 10^{-2}$	

Note :  $1.00 \times 10^{-3} \text{ mg}/\text{cm}^3 = 1.00 \text{ ppm}$

Conditions : column = 5 cm, h = 10 cm, cross-section area =  $19.63 \text{ cm}^2$ ,  
 flow rate =  $23.95 \text{ cm}^3/\text{min}$ ,  $v = 1.77 \text{ cm}/\text{min}$ ,  $N_0 = 1.77 \text{ mg}/\text{cm}^3$ ,  
 $k = 1.111948 \text{ cm}^3/\text{mg}\cdot\text{min}$ ,  $h_0 = 3.5 \text{ cm}$

APPENDIX B  
CHEMICAL REAGENTS

1. 4 % Hcl (V/V) : Dilute 40 ml of CONC. HCl to 1 L with distilled water in volumetric flask.
2.  $\text{Cd}^{2+}$  solution(50 ppm) : Weight 0.1143 g  $\text{CdSO}_4 \cdot 8\text{H}_2\text{O}$ , dissolve and dilute to 1 L with distilled water in volumetric flask.
3.  $\text{Cu}^{2+}$  solution (50 ppm) : Weight 0.196 g  $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ , dissolve and dilute to 1 L with distilled water in volumetric flask.

Note : 2. and 3. were determined accurate concentration by AA. spectro.

APPENDIX C

CALCULATION

C.1 Calculation of  $N_o$ ,  $k$ ,  $h_o$  of cadmium solution

$$C_o \quad 50 \quad \text{ppm} = 0.05 \quad \text{mg/cm}^3$$

$$C_B \quad 0.03 \quad \text{ppm} = 3 \times 10^{-5} \quad \text{mg/cm}^3$$

column  $\phi$  1.8 cm

$$\begin{aligned} \text{column cross-section area} &= \frac{\pi d^2}{4} \\ &= 2.54 \text{ cm}^2 \end{aligned}$$

flow rate of cadmium solution through the column

$$= 1.3, 2.0, 3.1 \text{ cm}^3/\text{min}$$

velocity of effluent through the column

$$= \text{flow rate/cross-section area}$$

$$= 0.51, 0.78, 1.22 \text{ cm/min respectively}$$

from plotted graph in Figure 9(a) with the ordinate being the break point time and the abscissa being the height of peat.

The linear curve of this relationship base on a surface-reaction-rate theory; Adamsand Bohart's equation :

from (2) section 2.3.3

$$t = N_o h / C_o v - 1 / C_o k [\ln(C_o / C_B - 1)]$$

calculation of  $N_o$ ,  $k$  and  $h_o$

(a) at  $v = 0.51 \text{ cm/min}$  slope = 39.5 intercept = 96

from (3) section 2.3.3

$$N_o = \text{slope} \times C_o \times v = 39.5 \times 0.05 \times 0.51$$

$$= 1.00725$$

$$\text{from (4) } k = \frac{1}{C_o \times \text{intercept}} \ln(C_o/C_B - 1)$$

$$= \frac{1}{0.05 \times 96} \ln\left(\frac{0.05}{3 \times 10^{-5}} - 1\right)$$

$$= 1.545412$$

$$\text{from (5) } h_o = \frac{v \ln(C_o/C_B - 1)}{kN_o}$$

$$= \frac{0.51}{1.545412 \times 1.00725} \ln\left(\frac{0.05}{3 \times 10^{-5}} - 1\right)$$

$$= 2.430379$$

(b) at  $v = 0.78$  cm/min slope = 28.2 intercept = 71

$$\text{from(3) } N_o = \text{slope} \times C_o \times v$$

$$= 28.2 \times 0.05 \times 0.78$$

$$= 1.0998$$

$$\text{from(4) } k = \frac{1}{C_o \times \text{intercept}} \ln(C_o/C_B - 1)$$

$$= \frac{1}{0.05 \times 71} \ln\left(\frac{0.05}{3 \times 10^{-5}} - 1\right)$$

$$= 2.089572$$

$$\text{from(5) } h_o = \frac{v \ln(C_o/C_B - 1)}{kN_o}$$

$$= \frac{0.78}{2.089572 \times 1.0998} \ln\left(\frac{0.05}{3 \times 10^{-5}} - 1\right)$$

$$= 2.517730$$

(c) at  $v = 1.22$  cm/min slope = 20 intercept = 62

$$\begin{aligned} \text{from(3)} \quad N_o &= \text{slope} \times C_o \times v \\ &= 20 \times 0.05 \times 1.22 \\ &= 1.22 \end{aligned}$$

$$\begin{aligned} \text{from(4)} \quad k &= \frac{1}{C_o \times \text{intercept}} \ln(C_o/C_B - 1) \\ &= \frac{1}{0.05 \times 62} \ln\left(\frac{0.05}{3 \times 10^{-5}} - 1\right) \\ &= 2.392897 \end{aligned}$$

$$\begin{aligned} \text{from(5)} \quad h_o &= \frac{v}{k N_o} \ln(C_o/C_B - 1) \\ &= \frac{1.22}{2.392897 \times 1.22} \ln\left(\frac{0.05}{3 \times 10^{-5}} - 1\right) \\ &= 3.1 \end{aligned}$$

### C.2 Calculation of $N_o$ , $k$ , $h_o$ of Copper Solution

$$C_o = 50 \text{ ppm} = 0.05 \text{ mg/cm}^3$$

$$C_B = 1 \text{ ppm} = 0.001 \text{ mg/cm}^3$$

Column  $\phi$  1.8 cm

$$\text{cross-section area of column} = \frac{\pi d^2}{4}$$

$$= 2.54 \text{ cm}^2$$

flow rate of copper solution through the column

$$= 2.5, 3.0, 4.5 \text{ cm}^3/\text{min}$$

velocity of effluent through column

$$= \text{flow rate/cross section area}$$

$$= 0.98, 1.18, 1.77 \text{ cm/min respectively}$$

from plotted graph in Figure 9(b) with the ordinate being the break point time and the abscissa being the height of peat.

The linear curve of this relationship base on a surface-reaction-rate theory ; Adams and Bohart's equation :

$$\text{from(2)} \quad t = N_o h / C_o v - 1 / C_o k [\ln(C_o / C_B - 1)]$$

calculation of  $N_o$ ,  $k$  and  $h_o$

$$\text{(a) at } v = 0.98 \text{ cm/min slope} = 32.3 \text{ intercept} = 76$$

$$\begin{aligned} \text{from (3)} \quad N_o &= \text{slope} \times C_o \times v \\ &= 32.3 \times 0.05 \times 0.98 \\ &= 1.5827 \end{aligned}$$

$$\begin{aligned} \text{from(4)} \quad k &= \frac{1}{C_o \times \text{intercept}} \ln(C_o / C_B - 1) \\ &= \frac{1}{0.05 \times 76} \ln\left(\frac{0.05}{0.001} - 1\right) \\ &= 1.024163 \end{aligned}$$

$$\text{from(5)} \quad h_o = \frac{v}{k N_o} \ln(C_o / C_B - 1)$$

$$= \frac{0.98}{1.024163 \times 1.5827} \ln\left(\frac{0.05}{0.001} - 1\right)$$

$$= 2.35238$$

(b) at  $v = 1.18$  cm/min slope = 28.5 intercept = 75

$$\text{from(3)} \quad N_o = \text{slope} \times C_o \times v$$

$$= 28.5 \times 0.05 \times 1.18$$

$$= 1.6515$$

$$\text{from(4)} \quad k = \frac{1}{C_o \times \text{intercept}} \ln(C_o/C_B - 1)$$

$$= \frac{1}{0.05 \times 75} \ln\left(\frac{0.05}{0.001} - 1\right)$$

$$= 1.037818$$

$$\text{from(5)} \quad h_o = \frac{v}{kN_o} \ln(C_o/C_B - 1)$$

$$= \frac{1.18}{1.037818 \times 1.6515} \ln\left(\frac{0.05}{0.001} - 1\right)$$

$$= 2.631578$$

(c) at  $v = 1.77$  cm/min slope = 20 intercept = 70

$$\text{from(3)} \quad N_o = \text{slope} \times C_o \times v$$

$$= 20 \times 0.05 \times 1.77$$

$$= 1.77$$

$$\text{from(4)} \quad k = \frac{1}{C_o \times \text{intercept}} \ln(C_o/C_B - 1)$$

$$= \frac{1}{0.05 \times 70} \ln(0.05 - 1)$$

$$= 1.111948$$

from(5)  $h_o = \frac{v}{kN_o} \ln(C_o/C_B - 1)$

$$= \frac{1.77}{1.111948 \times 1.77} \ln(0.05 - 1)$$

$$= 3.5$$

### C.3 Calculation of Column Efficiency from Adsorptive Capacity for Cadmium Solution

For example , velocity = 0.51 cm/min

$$C_o = 0.05 \text{ mg/cm}^3$$

$$C_B = 3 \times 10^{-5} \text{ mg/cm}^3$$

$$h = 3.5 \text{ cm}$$

from Table 5  $h_o = 2.430379$

$$k = 1.545412$$

$$N_o = 1.00725$$

replace these values in (8)

from (8)

$$\text{efficiency} = \frac{N_o h - v/k[\ln(C_o/C_B - 1)]}{N_o h} \times 100$$

$$= \frac{1.00725 \times 3.5 - 0.51/1.545412[\ln(0.05/3 \times 10^{-5}-1)]}{1.00725 \times 3.5} \times 100$$

$$= 0.305605$$

the same calculation for another two velocity and also as the calculation of column efficiency from adsorptive capacity for copper solution.

#### C.4 Calculation of Column Efficiency from Bed-height for Cadmium Solution

For example, velocity = 0.51 cm/min

$$h = 3.5 \text{ cm}$$

from Table 5  $h_o = 2.430379$

replace these values in (6)

from(6) , efficiency =  $\frac{h - h_o}{h}$

$$\begin{aligned} &= \frac{3.5 - 2.430379}{3.5} \\ &= 0.305605 \end{aligned}$$

the same calculation for another two velocity and also as the calculation of column efficiency from bed-height for copper solution.

#### C.5 Calculation of Treated Solution Volume for Cadmium Solution

For example, velocity = 0.51 cm/min

$$h = 3.5 \text{ cm}$$

$$C_o = 0.05 \text{ mg/cm}^3$$

$$C_B = 3 \times 10^{-5} \text{ mg/cm}^3$$



from Table 5  $N_o = 1.00725$

$$k = 1.545412$$

replace these values in (13)

from(13)  $t \times v = \frac{N_o h}{C_o} - \frac{v}{C_o k} [\ln(C_o/C_B - 1)]$

$$\begin{aligned} &= \frac{1.00725 \times 3.5}{0.05} - \frac{0.51}{0.05 \times 1.545412} [\ln(0.05 - 1)] \\ &= 21.5475 \end{aligned}$$

the same calculation for another two velocity and also as the calculation of treated solution volume for copper solution.