

**Chemical Inventory and Investigation of Treatment Methods for
Chemical Substances Used at Suranaree University of Technology**

Miss Nittaya Boontian

**A Thesis Submitted in Partial Fulfillment of the Requirements
for the Degree of Master of Engineering in Environmental Engineering**

Suranaree University of Technology

Academic Year 2001

การสำรวจและศึกษาวิธีการบำบัดสารเคมีที่ใช้ในมหาวิทยาลัยเทคโนโลยีสุรนารี

นางสาว นิตยา บุญเทียน

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Suranaree University of Technology council has approved this submitted in partial fulfillment of the requirements for the Master's Degree

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Nittaya Boontian

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CHAPTER I

INTRODUCTION

1.1 General

Wastes generated in the laboratories in universities and research institutes may contain various kinds of chemical substances which are hazardous to humans. These chemicals are extremely diverse and indefinite, although the quantity used is much less than that in industries. The risks from exposure to these chemicals are not clearly understood by users in most cases. Hazardous chemicals used without recognition of the risks have the potential of impairing the health of the user and resulting in environmental pollution if they are discharged without proper treatment (Shinoda, 1994). Therefore, laboratory researchers should have not only the knowledge of the toxicity of the chemicals used in the experiments but also the means for stabilizing the toxic substances to prevent environmental pollution (Tamaura, 1994).

In the past, many academic laboratories (as well as industrial laboratories) had inappropriate chemical waste disposal. University students and their professors frequently poured chemical waste down the drain or into garbage bins. Professors, their assistants, or custodial people might just pour the chemical waste on the ground in some isolated spot or in a quarry or a waterway. At many schools, some of these practices still go on (Sander, 1986).

At present, most of the chemical wastewater from Suranaree University of Technology (SUT) laboratories are discharged into the sewer system by students. In this way, the cost of waste treatment is much higher as the system has to treat a lot of washing water rather than chemical wastewater. Heavy metals-containing compounds are separated by types of chemicals and discharged into separate waste collection boxes before treatment. However, if the boxes are full, wastes are also discharged into the sewer system.

Various kinds of chemicals that are discharged from SUT laboratories can be harmful to human health and adversely affect the ecosystem and the environment. This research intended to investigate the methods that could solve the problems. The first part of this thesis consists of a development of chemical inventory and consideration of chemical quantity used in laboratories. In the second part, precipitation and adsorption methods were used to treat selected chemical wastes that are among the most-used chemicals at SUT.

1.2 Objectives

The objectives of this study are:

1. To categorize the chemicals used in SUT laboratories.
2. To investigate the treatment methods for major chemical wastes, using precipitation and adsorption.

1.3 Scope and Limitation of the Study

1. The inventory survey included chemical substances used in Suranaree University of Technology laboratories in the years 1994-1998.
2. Optimum amounts of coagulants were evaluated, using jar test, for maximum precipitation of heavy metals.
3. Adsorption by activated carbon was used to remove organic substances.

CHAPTER II

LITERATURE REVIEW

2.1 Categories of Chemical Wastes in Laboratories

Reagents used in academic research laboratories are changed in quality and quantity and eventually they become waste materials. Surplus reagents generated in academic research laboratories also become wastes unless they are reused and recycled. Thus, the effective use of reagents is the key point in chemical waste management in laboratories. Establishment of an inventory control system in each laboratory is very important, and each university or institute should take the responsibility to see if it is implemented (Kaseno, 1994).

In addition, the great variety of waste generated by academic labs requires them to do an exceptional amount of paperwork to keep tabs on what they ship to off-site disposal facilities. This also is a serious problem for waste disposal firms. The waste disposal firm that Washington State University has used for many years recently notified the university that it no longer would handle the school's chemical waste. The company claimed that, although the university's waste represented only about 1% of the company's business, it accounted for about 99% of the company's problems (Sander, 1986). The hazardous wastes generated by academic labs range from organic solvents, heavy metals, and explosives to flammable compounds, toxic materials, corrosive substances, and carcinogens. Typically, the largest volume of waste generated by these labs consists of organic solvents (Sander, 1986).

In general, reagents in typical laboratories can be categorized into 4 groups: (1) inorganic reagents containing heavy or other metals, (2) inorganic reagents containing carcinogen compounds, fluorine, or phosphorus anion, (3) inorganic reagents containing alkalis or acids, and (4) organic reagents (Kaseno, 1994). However, different classifications are also used. A group of researchers for management of environment and hazardous materials at Chulalongkorn university classified

chemicals by treatment methods. Chemical wastewater were categorized into 12 groups: (1) special waste, (2) cyanide-containing waste, (3) oxidant (oxidizing waste), (4) mercury-containing, (5) chromate waste, (6) heavy metals containing waste, (7) acidic waste, (8) alkaline waste, (9) petroleum products, (10) hydrocarbon containing only C, H, and O, (11) hydrocarbon containing only N, S, and P, and (12) halogenated hydrocarbon waste (Phongsapit, 1999). Prince of Songkla university also uses this classification for its chemical wastes management (Kaewborisut et al, 1998).

2.2 Methods of Chemical Wastes Treatment

Wastes, once discharged, may be treated by improper incineration or simply disposed of on land. Such treatment and disposal can lead to environmental pollution. In selecting a chemical waste treatment technology, therefore, it is essential to ensure that the processed waste will not adversely affect human health or the living environment on either a short- or long-term basis. There are many treatment methods available; for example, incineration/thermal decomposition, melting, solidification, sanitary landfill, precipitate aggregation method (Takatsuki and Sakai, 1994) and adsorption (Metcalf & Eddy, 1991).

The numerous treatments applicable to chemical wastes can typically be categorized as chemical, physical, or biological in nature. Many such processes are already widely used to manage chemical wastes and have broad acceptance from government, industry, and public alike. Combinations of these treatment technologies are often utilized to develop the most cost-effective and environmentally acceptable solutions to waste management problems. Treatment processes may also be used to advantage in by-product recovery processes and in the volume reduction of wastes that ultimately must be disposed of. All “end-of-the-pipe” wastes should first be surveyed and characterized to determine the applicability of various treatment and destruction processes (Wentz, 1989).

The following two methods of chemical waste treatment were considered in this study.

2.2.1 Precipitate Aggregation Method

Wastewater discharged from chemical laboratories includes not only heavy metals but also high concentrations of salts or organic compounds. The precipitate aggregation method is a classical and well-known treatment technique. The process for removing heavy metals in wastewaters is as follows: (1) heavy metals are precipitated as water-insoluble hydroxides or sulfides, (2) precipitated sludge is separated from the treated water, and (3) heavy metals in the treated water are removed by adsorbing on chelate resins (Kitamura, 1994).

Undesirable heavy metals are often present in liquid waste streams. The heavy metals must be removed if their concentrations are so high that the waste stream is designated as hazardous according to the Extraction Procedure (EP) toxicity characterization as described in the Resource Conservation and Recovery Act (RCRA). The usual method for removal of inorganic heavy metals is chemical precipitation. The metals are precipitated at varying pH levels, depending upon the metal ion, resulting in the formation of an insoluble salt. Hence, neutralization of an acidic waste stream can cause precipitation of heavy metals and allow them to be removed as a sludge residue by clarification, sedimentation, or filtration (Wentz, 1989).

Hydroxides of heavy metals are usually insoluble, so lime is commonly used for precipitating them. Carbonates or sulfides are less soluble than hydroxides. Economic reasons may justify partial precipitation with lime to the solubility level of the hydroxide, followed by a secondary treatment with sulfide for further reduction (Wentz, 1989). Metal hydroxide sludges are produced in the removal of metals such as lead, chromium, nickel, and zinc from wastewater by raising the pH to such a level that the corresponding hydroxides or hydrated metal oxides are precipitated (Manahan, 1993).

(a) Hydroxide Precipitation

The theoretical foundation for removing heavy metals from wastewater by the precipitate aggregation method has already been established (Kitamura, 1994). Most heavy metal hydroxides have minimal solubility in a high pH region; therefore, they are precipitated by adding alkali to the wastewater. The equilibrium relationship can be written as



where M is a metal. The solubility product $K_{sp} = [M^{n+}][OH^{-}]^n$ and the ionic product $K_w = [H^{+}][OH^{-}]$ are given by

$$[M^{n+}] = K' [H^{+}]^n \quad (2-2)$$

where $K' = \frac{K_{sp}}{K_w^n}$

When the metal M forms an amphoteric hydroxide, the equilibrium relationship can be written as



if alkali exists in excess. In the equilibrium state for forming hydroxide complex ions, the equilibrium constant K can be written as

$$K = [H^{+}][H_{n-1}MO_n^{-}] \quad (2-4)$$

From Equations (2-2) and (2-4), the dissolved heavy metal concentration C_M can be represented as follows:

$$C_M = [M^{n+}] + [H_{n-1}MO_n^{-}] = K' [H^{+}]^n + \frac{K}{[H^{+}]} \quad (2-5)$$

Therefore, in simple systems, the dissolved heavy metal concentration C_M is determined by the pH value. However, the solubility of metal hydroxides changes with the conditions (i.e., temperature, ionic strength, aging time, and coexistent salts). Actual wastewater contains many kinds of coexistent compounds. Therefore, the removal limit of heavy metals cannot be determined simply by using the pH value.

It is necessary to adjust the value of pH to the most suitable range to remove the heavy metals as hydroxides. The buffer exponent such as the amount of alkali to be added and the degree of difficulty in adjusting pH of the wastewater can be determined by observing the titration curves of the neutralization. Generally, these curves are made up in a preliminary experiment before disposal of the wastewater (Kitamura, 1994).

(b) Coagulation and Flocculation

The precipitation process of heavy metals can be greatly enhanced through addition of various water-soluble chemicals and polymers that promote coagulation and flocculation. Coagulation and flocculation are used to separate suspended solids from liquids when their normal sedimentation rates are too slow to provide effective clarification. These are two different but related mechanisms in clarification and dewatering (Wentz, 1989).

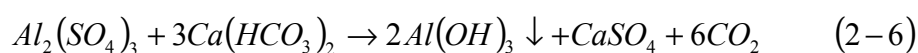
Coagulation and flocculation are greatly influenced by physical and chemical forces such as electrical charges on particles, exchange capacity, particle size and concentration, pH, water temperature, and electrolyte concentrations. These and other factors vary widely from place to place and their influence and effects are not fully understood. Because of this, it is important to secure information on the behavior of the water, and by laboratory testing using “jar test” techniques, followed by laboratory filtration (ASCE and AWWA, 1971).

Selection of the type and dose of coagulant depends on the characteristics of the coagulant, the particulates, and the water quality. The interdependence between these three elements may be understood qualitatively; however, prediction of the optimum

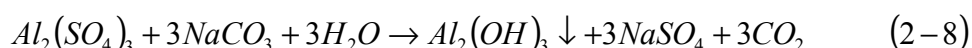
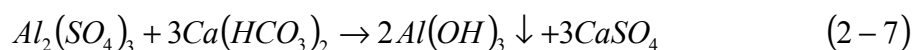
coagulant combination from characteristics of the particulates and the water quality is not yet possible. As a result, each coagulation problem must be solved empirically (James M. Montgomery, 1985).

Aluminum sulfate is employed more frequently than iron salts in water treatment clarification because it is usually cheaper, but iron salts are effective over a wider pH range. In the lime-soda softening process, lime serves as a coagulant to produce a heavy precipitate consisting of calcium carbonate and magnesium hydroxide, which has coagulating and flocculating properties (Wentz, 1989).

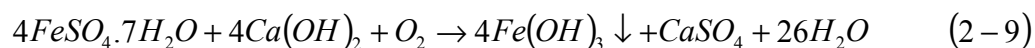
The principal factors affecting the coagulation and flocculation of wastewater are suspended solids, pH, and the dosage and nature of the coagulant. The wastewater must be alkaline for aluminum sulfate to produce aluminum hydroxide:



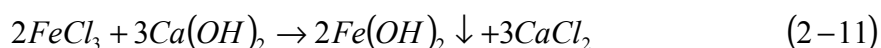
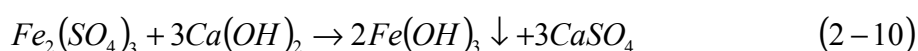
If the wastewater does not have sufficient alkalinity to react with the alum, it must be added in the form of calcium hydroxide (lime) or sodium carbonate (soda ash):



Ferrous sulfate treatment also requires alkalinity in the wastewater. Lime is usually added to raise the pH above 9.5 where ferrous ions are precipitated as ferric hydroxide:



Ferric sulfate and chloride may also be used:



Gregor et al (1997) investigated a method of optimized natural organic matter removal from low turbidity waters by controlling pH adjustment of aluminium coagulation. Effective removal of soluble natural organic matter (NOM) from low-turbidity waters could be achieved by aluminium coagulation provided that attention was paid to micro-floc formation (coagulation) and macro-floc development (flocculation). This work provides guidelines and an explanation of how pH should be controlled to maximize soluble NOM removal while at the same time making full use of pH-influencing chemical (acid, alum, and lime). For low-turbidity waters, essential floc nucleating sites can be provided by the lime that was used for pH and alkalinity adjustment, provided that the lime was added in sufficient quantity and at a point where it retained some of its particulate nature; i.e., immediately after coagulant addition. Adjusting the pH downwards to between 4 and 5 prior to coagulant addition allowed the formation of soluble NOM-aluminium complexes that linked to each other, thereby forming large insoluble bridged complexes (micro-flocs) that also acted as nuclei for macro-floc development (flocculation).

Stephenson and Duff (1996) conducted a study to examine the effects of metal coagulant concentration, effluent dilution and pH on the removal of total carbon, color and turbidity from a combined bleached chemithermomechanical/thermomechanical (BCTMP/TMP) effluent. Both chloride and sulphate salts of iron and aluminum were effective in treating the mechanical pulping effluent in batch jar screening test. The pH had a pronounced effect on precipitation. In terms of minimizing the total carbon (TC), color and turbidity levels, the optimum adjusted pH ranges were: 4.0-6.5 for ferric chloride, above 7.4 for ferrous sulphate, 5.0-6.0 for aluminum chloride and 5.8 to 6.8 for aluminum sulphate. Removal of TC, color, and turbidity of up to 88%, 90% and 98%, respectively, were observed. The precipitation yielded a supernatant which was clear and colorless.

Garrote et al (1995) developed a method for treatment of tannery effluents by a two step coagulation/flocculation process. A coagulation/flocculation method for the treatment of tannery effluents was described in which alkaline FeCl_3 was used as flocculating agent and $\text{Ca}(\text{OH})_2$ as base/precipitant. Two cycles of the treatment

reduced the chemical oxygen demand (COD) of the effluent by 87%, producing a colorless, odorless wastewater with no appreciable suspended solids. Further repetition produced no further reduction in the COD.

2.2.2 Adsorption

Adsorption, in general, is the process of collecting soluble substances that are in solution on a suitable interface. The interface can be between the liquid and a gas, a solid, or another liquid. Only the case of adsorption at the liquid-solid interface is considered in the following discussion.

Adsorption employs the capacity of an adsorbent to remove certain substances from a solution. Activated carbon is an adsorbent that is widely used in water treatment, advanced wastewater treatment, and the treatment of certain organic industrial wastewaters because it adsorbs a wide variety of organic compounds and its use is economically feasible. In water treatment, it is used to remove compounds that cause objectionable taste, odor, or color. In advanced wastewater treatment, it is used to adsorb dissolved organic compounds, and in industrial wastewater treatment it is mainly used to adsorb toxic organic compounds. It is generally used in granular form in batch, column (both fixed bed and countercurrent bed), or fluidized-bed operations, with fixed-bed columns being the most common. Occasionally, activated carbon is used in powdered form and is not recovered for regeneration; however, such application is usually limited to water treatment where the amounts of carbon used are not appreciable. Adsorbents other than activated carbon are used to a lesser extent in environmental engineering (Reynolds and Richards, 1996).

Adsorption may be classified as (1) physical adsorption or (2) chemical adsorption. Physical adsorption is primarily due to van der Waals forces and is a reversible occurrence. When the molecular forces of attraction between the solute and the adsorbent are greater than the forces of attraction between the solute and the solvent, the solute will be adsorbed onto the adsorbent surface. An example of physical adsorption is the adsorption by activated carbon. Activated carbon has numerous capillaries within the carbon particles, and the surface available for

adsorption includes the surfaces of the pores in addition to the external surface of the particles. Actually, the pore surface area greatly exceeds the surface area of the particles, and most of the adsorption occurs on the pore surfaces. For activated carbon the ratio of the total surface area to the mass is extremely large. In chemical adsorption, a chemical reaction occurs between the solid and the adsorbed solute, and the reaction is usually irreversible. Chemical adsorption is rarely used in environmental engineering and therefore is not discussed in this section (Reynolds and Richards, 1996).

Activated carbon can be made from a variety of carbonaceous raw materials such as wood, sawdust, fruit pit and coconut shells, coal, lignite, and petroleum base residues. Processing is dehydration and carbonization by slow heating in the absence of air followed by chemical activation to produce a highly porous structure (Viessman and Hammer, 1998).

(a) Treatment with Granular Activated Carbon (GAC)

A fixed-bed column is often used as a means of contacting wastewater with GAC. The water is applied to the top of the column and withdrawn at the bottom. The carbon is held in place with an underdrain system at the bottom of the column. Provision for backwashing and surface washing is usually necessary to limit the headloss buildup due to the removal of particulate material within the carbon column. Fixed-bed columns can be operated singly, in series, or in parallel (Metcalf & Eddy, 1991).

(b) Treatment with Powered Activated Carbon (PAC)

An alternative means of application is that of adding PAC. Powdered activated carbon can be added to the effluent from biological treatment processes, or added directly into various biological treatment processes. In the case of biological-treatment-plant effluent, PAC is added to the effluent in a contacting basin. After a certain amount of time for contact, the carbon is allowed to settle to the bottom of the tank, and the treated water is then removed from the tank (Metcalf & Eddy, 1991).

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 adsorbed is determined as a function of the concentration at constant temperature, and the resulting function is called an adsorption isotherm. The Freundlich isotherm, which is an empirical formulation, frequently represents the adsorption equilibrium over a limited range in solute concentration (Ray, 1995). This empirically derived isotherm is defined as follows.

$$\frac{x}{m} = K_f C_e^{\frac{1}{n}} \quad (2-12)$$

Where

$\frac{x}{m}$ = amount adsorbate adsorbed per unit weight of adsorbent(carbon)-for example, g/g

C_e = equilibrium concentration of adsorbate in solution after adsorption-for example, g/L

K_f, n = empirical constants

The constants in the Freundlich isotherm can be determined by plotting (x/m) versus C_e and making use of Eq. (2-12) rewritten as

$$\log\left(\frac{x}{m}\right) = \log K_f + \frac{1}{n} \log C_e \quad (2-13)$$

Karimi-Jashni and Narbaitz (1997) investigated the impact of pH on the adsorption and desorption kinetics of 2-nitrophenol on activated carbons. The adsorption and desorption kinetics of 2-nitrophenol (2NP) from aqueous solutions using F-40 and WV-B granular activated carbons (GAC) was studied at pH 1, 4.6, and 13, using batch tests. Adsorption and desorption kinetics of 2NP on to both carbons were adequately described by the homogeneous solid surface diffusion model (HSSD). The adsorption and desorption kinetics can be predicted at different pH by using adsorption kinetics parameters of the pH 4.6 and the isotherm parameters for the

corresponding pH. Thus, the differences in the rates of adsorption were primarily attributable to the differences in the equilibrium loading at the various pH values.

A steady-state model, based on the concept of homogeneous surface diffusion, was developed by Traegner et al (1996) to describe an activated-carbon adsorber with continuous carbon replacement. Both age and size distributions of carbon particles were incorporated into the model. Using the resulting closed-form solution, a series of simulations was made to investigate the effects of adsorption characteristics, the average of carbon particles, surface diffusion coefficient, particle size and carbon concentration on the effluent adsorbate concentration. Although there is no single and equivalent particle size that can truly represent a particle size distribution, the use of a carefully chosen equivalent particle size could lead to less than 10% errors in adsorber performance predictions. Unfortunately, there is no formal protocol for selection of the equivalent particle size and trial-and-error iterations are necessary.

Single-solute irreversible adsorption on granular activated carbon was investigated by Yonge et al (1985). Irreversible adsorption has been shown to influence activated carbon adsorption equilibria. To gain a better understanding of irreversible adsorption and its influence on adsorption equilibria, batch and continuous-flow single-solute adsorption experiments were conducted on five low molecular weight substituted phenol. Sorbate functional group type and position were shown to influence the degree of irreversible adsorption. Furthermore, the occurrence of irreversible adsorption was shown to influence the shape of the isotherm trace depending on the experimental procedure used for isotherm development.

Peel and Benedek (1980) investigated attainment of equilibrium in activated carbon isotherm studies. Their paper examines the adsorption of phenol and o-chlorophenol from aqueous solution onto activated carbon. The results show that granular activated carbon took up to 3 weeks to reach equilibrium with phenol and up to 5 weeks to reach equilibrium with o-chlorophenol. Powdered carbon isotherms took from 3 to 5 days to reach equilibrium. Up to 80% of the adsorptive equilibrium was reached in the first few hours, but the remaining capacity was utilized very

slowly. This type of behavior can be described by a dual rate mechanism macropore-micropore adsorption model, which can be used to explain variations in isotherm behavior previously reported in the literature. The study clearly shows that extended contacting periods should be allowed during isotherm evaluations to ensure that equilibrium is obtained. Wherever possible, powdered carbon isotherms should be used instead of granular carbon isotherms.

In a study performed by Martin and Al-Bahrani (1979), gas-liquid chromatography with a flame ionization detector system using the direct injection of aqueous solutions was used to monitor the adsorption of selected organic compounds dissolved in water onto activated carbon. The effects of competitive adsorption in bisolute solution systems were investigated. In general, the higher molecular weight compound was more favourably adsorbed because of the higher affinity of the larger molecule to the carbon surface.

CHAPTER III

METHODOLOGY

3.1 Classification of Chemicals Used in SUT Laboratories

Information on the categories and quantities of chemical substances used in Suranaree University of Technology (SUT) laboratories were obtained from the Division of Procurement & Supplies of SUT for the duration 1994-1998. Chemical compounds in the inventory list were grouped into 5 categories, namely: (1) carbon-containing compounds, (2) nitrogen-containing compounds, (3) phosphorus-containing compounds, (4) sulfur-containing compounds, and (5) metal-containing compounds. Note that the categories overlap since some compounds contain chemical substances of two or more categories. For example; urea $[(\text{NH}_2)_2\text{CO}]$ is placed in both carbon and nitrogen-containing categories.

Ten substances that were used in the largest quantities are: methanol $[\text{CH}_3\text{OH}]$, acetone $[\text{CH}_3\text{COCH}_3]$, ethanol $[\text{C}_2\text{H}_5\text{OH}]$, acetic acid $[\text{CH}_3\text{COOH}]$, ally alcohol $[\text{CH}_2\text{CHCH}_2\text{OH}]$, ethyl acetate $[\text{CH}_3\text{COOC}_2\text{H}_5]$, n-Hexane $[\text{CH}_3(\text{CH}_2)_4\text{CH}_3]$, isopropanol $[\text{CH}_3\text{CHOHCH}_3]$, copper $[\text{Cu}]$, and zinc $[\text{Zn}]$. In view of the available apparatus in Environmental Engineering laboratory at the Center of Scientific Equipment Building 5 in SUT, acetic acid, ethyl acetate, Cu, and Zn were chosen for the investigations through precipitation and adsorption experiments in this study.

3.2 Precipitation Experiments

A synthetic wastewater was made by mixing $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ and $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$ with tap water. In order to determine the optimum Cu and Zn concentrations for Atomic Adsorption Spectrometer (AAS) detection, the samples were prepared by varying concentrations of Cu and Zn from 10-60 ppm, 2-12 ppm, respectively and the pH adjustment to 7.0 was made by addition of lime. From these preliminary tests, the optimum concentrations were chosen as 40 ppm for Cu and 10 ppm for Zn. The concentrated stock solutions of ferric chloride and aluminium sulphate were prepared

at a concentration of 1 g/L by dissolving analytical reagent-grade $\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$ and $\text{Al}_2(\text{SO}_4)_3 \cdot 18\text{H}_2\text{O}$, respectively, in deionized water .

All experiments were conducted at room temperature (average of $28 \pm 1^\circ\text{C}$). A Phipps and Bird six-paddle mechanical stirrer (illustrated in Figure 3-1) was used to simulate the rapid mixing and flocculation operations of a conventional wastewater treatment plant. The stirrers of the jar-test machine were set to turn at approximately 120 rpm for rapid mixing. After two minutes of rapid mixing, the stirrers were turned to 20 rpm to allow slow mixing for 20 min. The stirrers were then stopped, and the solution was allowed to settle for 20 min. A 50 mL sample was piped from a beaker at the depth of 4 cm from the sample surface (Jeffcoat and Singley, 1975). Samples for analysis were prepared by filtration. The separation was performed by using micropore (0.45- μm) filtration unit designed to hold 47-mm diameter filter disks. Filtrate was utilized for analysis of Cu and Zn residual concentrations by AAS.

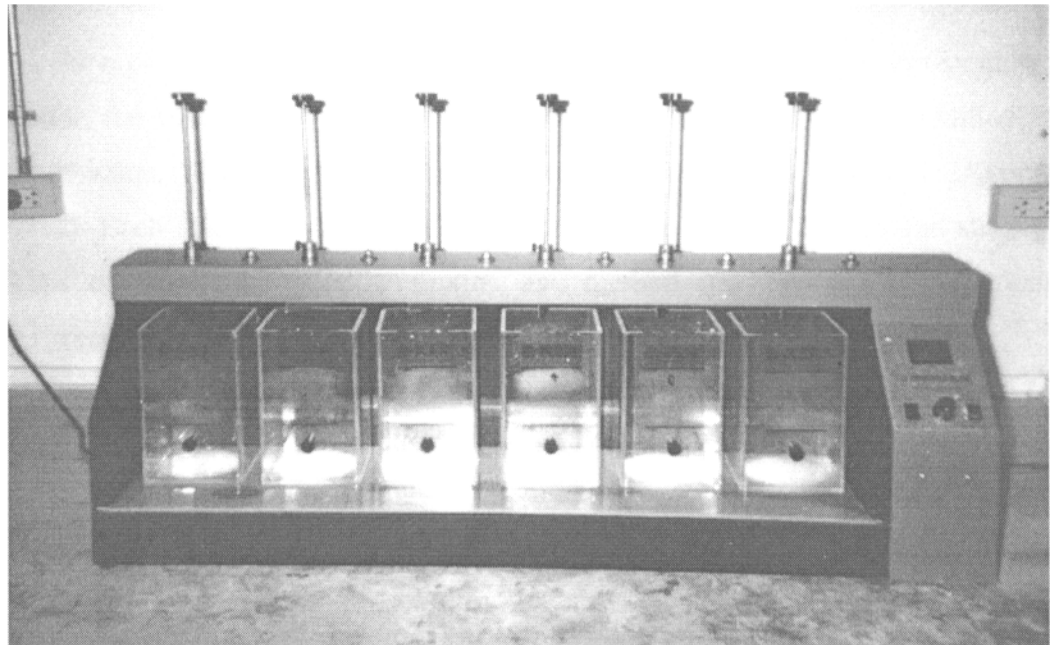


Figure 3-1. A phipps and bird six-paddle mechanical stirrer.

3.2.1 The Effect of pH

In order to study the effect of pH, the optimum conditions were ascertained by performing a series of jar tests. The synthetic wastewater was prepared at the optimum concentrations of Cu and Zn of 40 ppm and 10 ppm, respectively. From this solution, 500 mL samples were taken and placed in six 1-L beakers.

Prior to the experiment, the amounts of lime and HCl needed to adjust the pH were determined empirically with the use of a digital Metrohm 744 pH meter, which was calibrated by phosphatic buffers at pH 7 and 4. In order to determine the optimum pH, which caused flocs formation and low residual concentrations, pre-determined amounts of a saturated lime solution (10 mg as CaCO_3/L) and hydrochloric [HCl] acid (0.01 moles/L) were added to each of the six beakers resulting in different pH for the 6 samples. The pH varied from 4.0, 4.5, ..., 12.5 and two samples were prepared at each pH value. The steps of rapid mixing, slow mixing and method for residual concentrations analysis were same as in Section 3.2. The obtained optimum pH was used in the following steps as given in Sections 3.2.2 and 3.2.3.

3.2.2 The Effect of Alum Concentration

In order to evaluate the effect of alum coagulant dosage on the synthetic wastewater, the pH of the wastewater was first adjusted with dropwise addition of lime to the value. Alum solutions with concentration between the range of 1-240 ppm were used. Each solution was poured into each beaker during a 2-min rapid stirring. The steps of rapid mixing, slow mixing and method for residual concentrations analysis were same as those described above.

3.2.3 The Effect of Ferric Chloride

In order to investigate the effect of ferric chloride coagulant on precipitation, coagulation experiments were conducted by using ferric chloride with concentration ranging from 0.2-26.0 ppm. Ferric chloride was added from a prepared coagulant solution concentration of 1 g/L. Lime was added first into each beaker to adjust for optimum pH and then ferric chloride was added during a 2-min rapid stirring.

3.3 Adsorption Experiments

The two sorbates used in the batch adsorption experiments were acetic acid [CH₃COOH] and ethyl acetate [CH₃COOC₂H₅]. Sorbate stock solutions were prepared at 1 mole/L with distilled water at pH 7.0±0.1. Samples required for each adsorption experiment were prepared from the above stock solutions by dilution.

Coconut shell based granular activated carbon with particle size 0.60-2.36 mm was used as adsorbent in adsorption experiments. To facilitate shorter equilibration times, this GAC was washed with distilled water to remove carbon fines, dried at 105°C, and stored in a sealed glass bottle. The adsorption experiments were performed in batch and continuous operations.

3.3.1 Acetic acid and Ethyl acetate Adsorption Isotherms

Isotherm studies were conducted to estimate the acetic acid and ethyl acetate adsorption capacities on activated carbon. Freundlich isotherm is used in this study. The empirically derived Freundlich isotherm is defined as follow.

$$\frac{x}{m} = K_f C_e^{\frac{1}{n}} \quad (2-12)$$

Where

$\frac{x}{m}$ = amount adsorbate adsorbed per unit weight of adsorbent(carbon)-for
example, g/g

C_e = equilibrium concentration of adsorbate in solution after adsorption-for
example, g/L

K_f, n = empirical constants

The constants in the Freundlich isotherm can be determined by plotting (x/m) versus C_e and making use of Eq. (2-12) rewritten as

$$\log\left(\frac{x}{m}\right) = \log K_f + \frac{1}{n} \log C_e \quad (2-13)$$

Varying amounts of 1, 2, ..., 8 g of activated carbon for acetic acid isotherm and 2, 3, ..., 8 g of activated carbon for ethyl acetate isotherm were added to the 500 mL flasks sealed with teflon-lined screw caps as shown in Figure 3-2 (5-flasks for acetic acid samples and 7-flasks for ethyl acetate samples, respectively). From the preliminary tests, acetic acid and ethyl acetate concentrations were chosen at 0.14 and 0.10 moles/L, respectively, for investigation in adsorption experiments, because concentration lower than that could not be detected by High-Performance Liquid Chromatography (HPLC) when equilibrium occurred. The initial pH were 3.16 for acetic acid and 4.20 for ethyl acetate. The solutions of varying concentrations of acetic acid and ethyl acetate were prepared from the stock solution. Five hundred milliliters of the each sample solution was put in each flask. Experiments were carried out at a controlled temperature of $28\pm 1^\circ\text{C}$. The solution in the sealed flasks were agitated at 200 rpm in a rotary shaker. Samples for sorbate analysis were prepared by filtration to separate the liquid and solid phases. The separation was performed by using an all-glass Millipore filtration unit designed to hold 47 mm diameter filter disks to remove activated carbon particles. The amount of acetic acid and ethyl acetate contents in the filtrates were analyzed by using HPLC. The preliminary adsorption tests showed no detectable change in liquid-phase sorbate

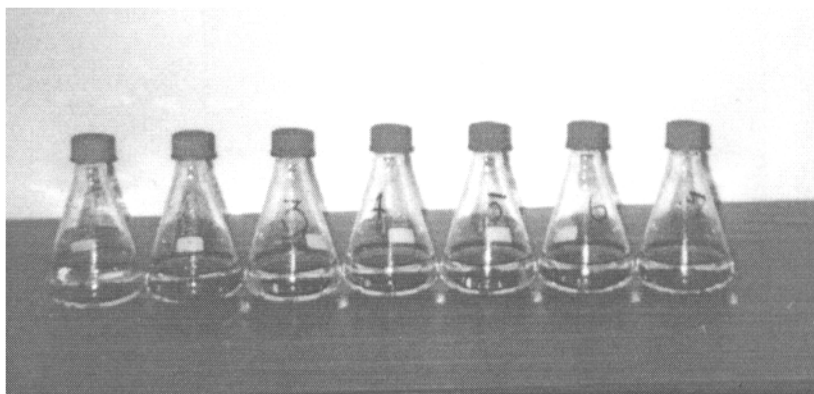


Figure 3-2. 500 mL flasks for containing synthetic wastewater in batch-adsorption experiments.

concentration after 17 days. A 3-day safety factor was added, resulting in the 20-days period to achieve equilibrium conditions.

3.3.2 Fixed-Bed Adsorption Columns Experiments

The experimental set-up is shown in Figure 3-3. A 15-L volumetric container was used to hold sorbate solution prepared by mixing the individual solutions of acetic acid and ethyl acetate concentrations of 0.14 and 0.10 moles/L, respectively. A plastic column with 7.5-cm diameter and 25-cm height was used to hold granular activated carbon (GAC). Four hundred grams of GAC was added to the plastic column. The bottom of the plastic column had a pore for the solution to pass through to the beaker underneath.

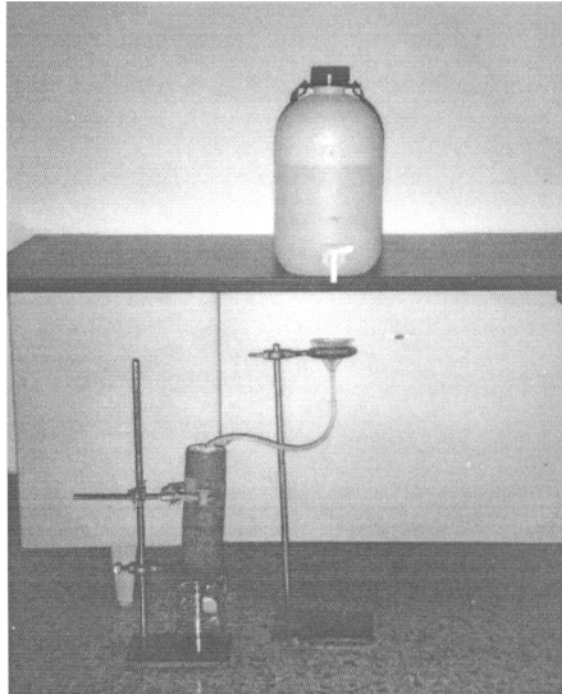


Figure 3-3. The experimental set-up for continuous-adsorption experiments.

The flow rate was maintained through the plastic column using a valve controller at the outlet of the volumetric container. During adsorption, the influent sorbate concentrations were introduced in column in a down ward flow from top to bottom. The effluent from the plastic column bottom was collected every 5-30 minutes by using vials to contain sorbate. Then, the sorbate concentrations were examined. The operation was continued until the influent and effluent sorbate concentrations were not significantly different.

CHAPTER IV

RESULTS AND DISCUSSIONS

4.1 Classification of Chemicals Used in SUT Laboratories

Details of chemicals purchased by Suranaree University of Technology used in laboratories between the years 1994 to 1998 are shown in appendix A. These chemicals can be classified into 2 groups, solid and liquid. They were also classified into 5 categories based on the chemical-containing: (1) carbon-containing compounds, (2) nitrogen-containing compounds, (3) phosphorus-containing compounds, (4) sulfur-containing compounds, and (5) metal-containing compounds. It was found that in 1998, the two main groups of chemicals used were inorganic compounds containing 2,250 g of Cu and 5,000 g of Zn, and organic compounds containing 37,000 mL of acetic acid and 20,250 mL of ethyl acetate.

Figures 4-1 to 4-5 show the quantity and volume of each category of chemical containing compounds that were used during the years 1994-1998. For the year 1994 the record of the used chemicals in liquid form is not available as it was the first academic year of the university. Figure 4-6 shows the comparison between the amounts of chemicals used in solid and liquid forms in the year 1998.

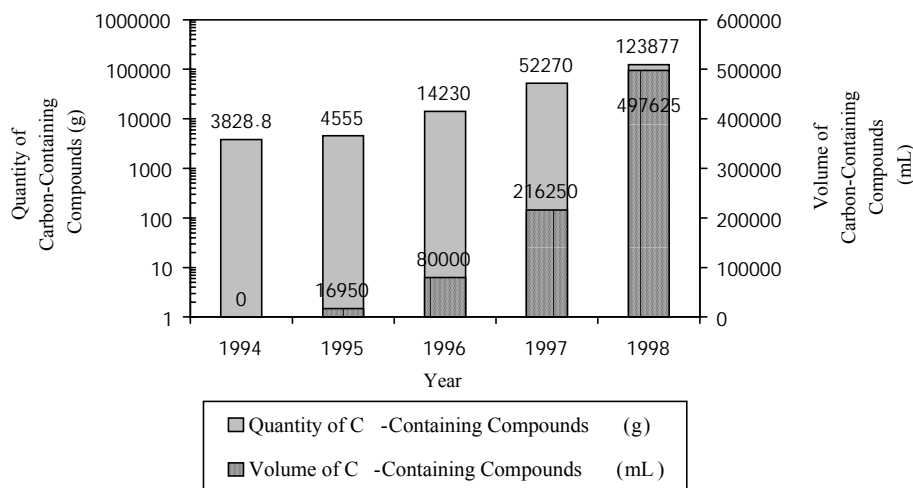


Figure 4-1. The carbon-containing compounds used in the years 1994-1998.

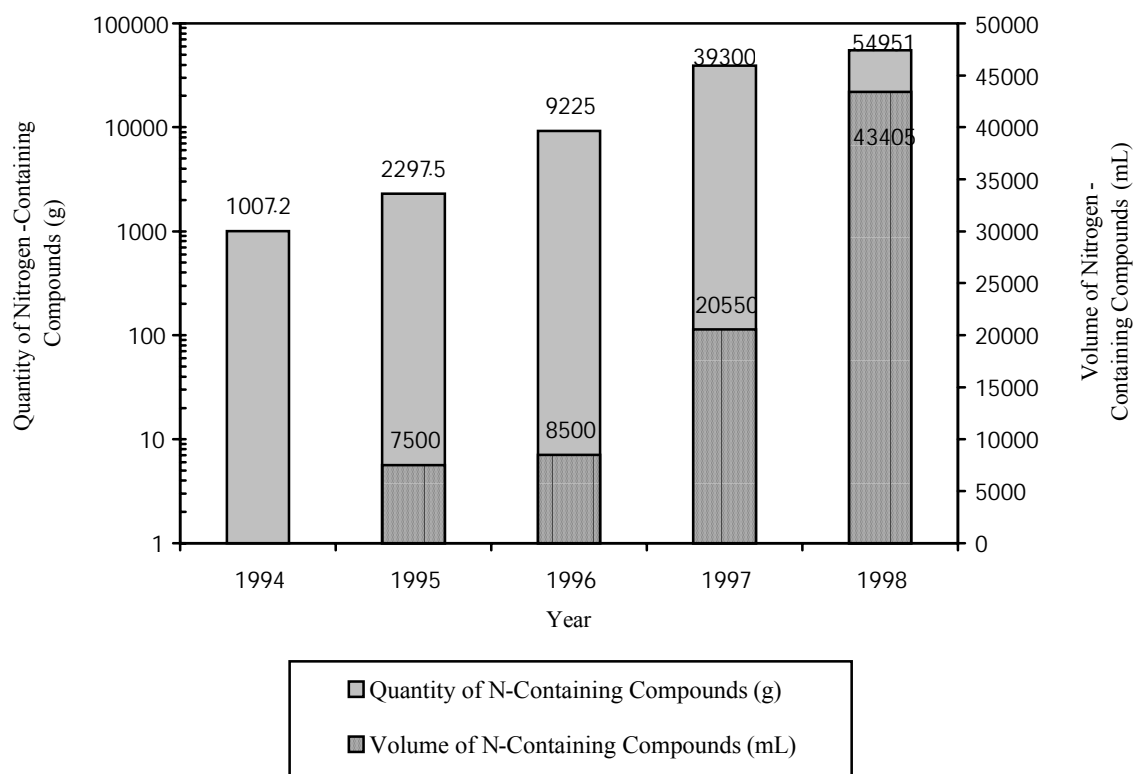


Figure 4-2. The nitrogen-containing compounds used in the years 1994-1998.

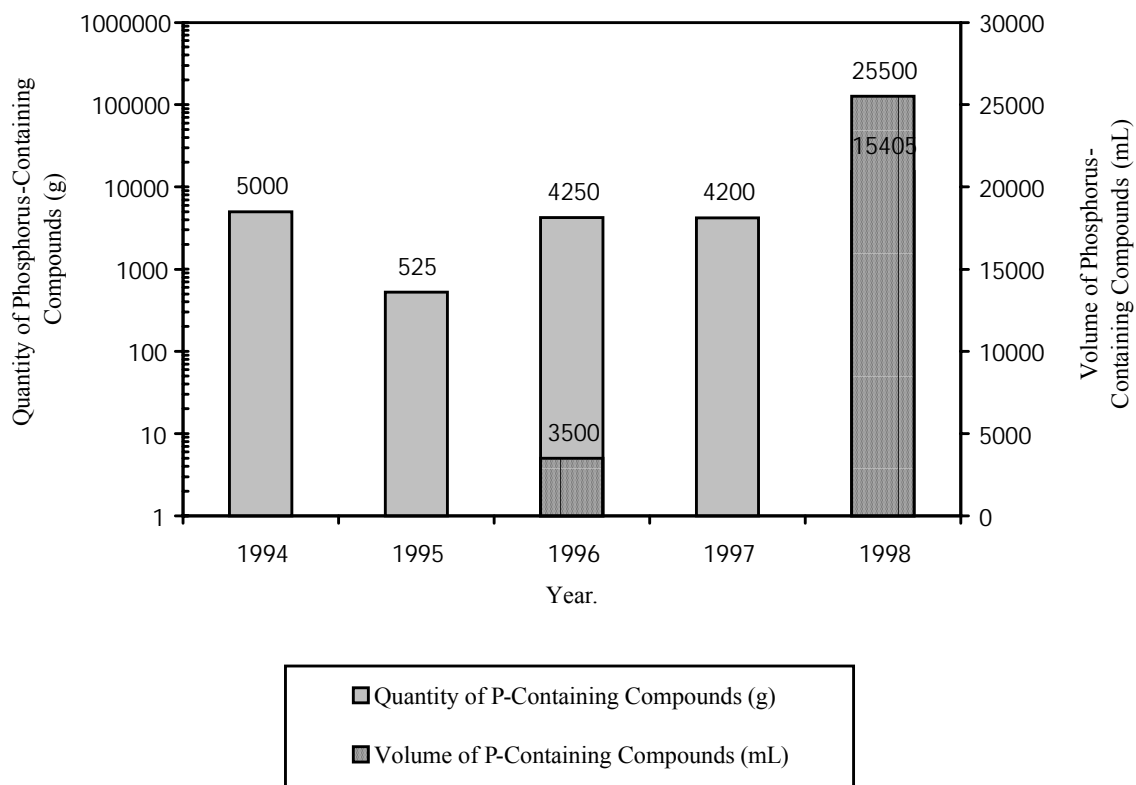


Figure 4-3. The phosphorus-containing compounds used in the years 1994-1998.

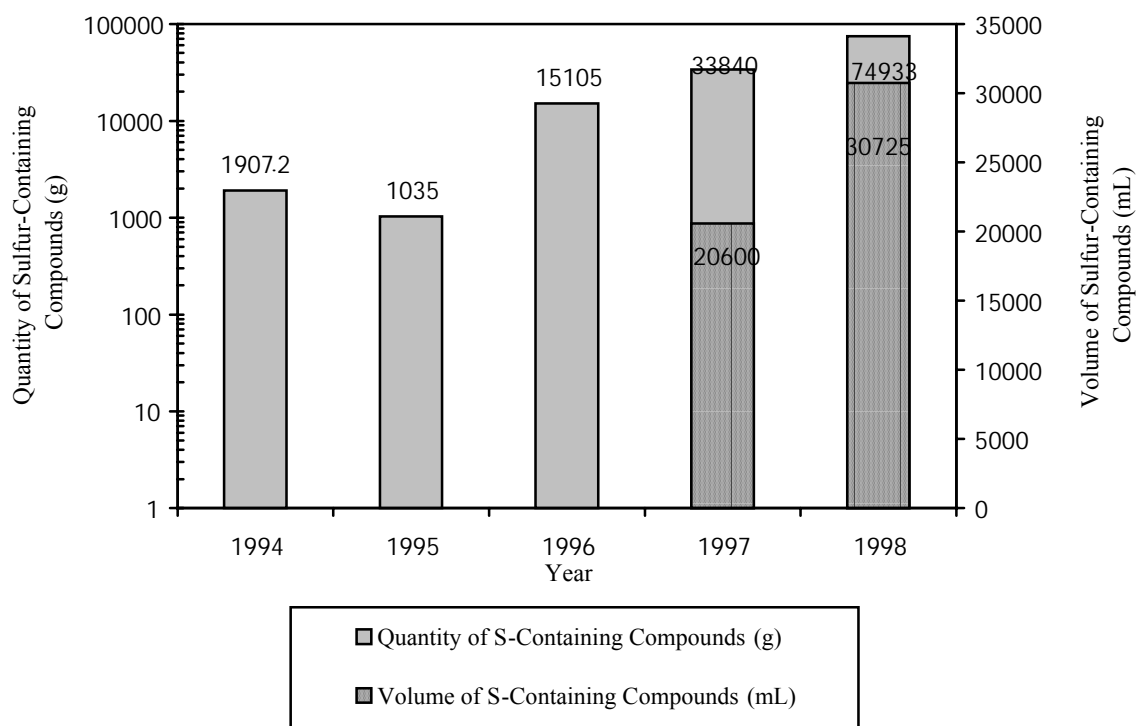


Figure 4-4. The sulfur-containing compounds used in the years 1994-1998.

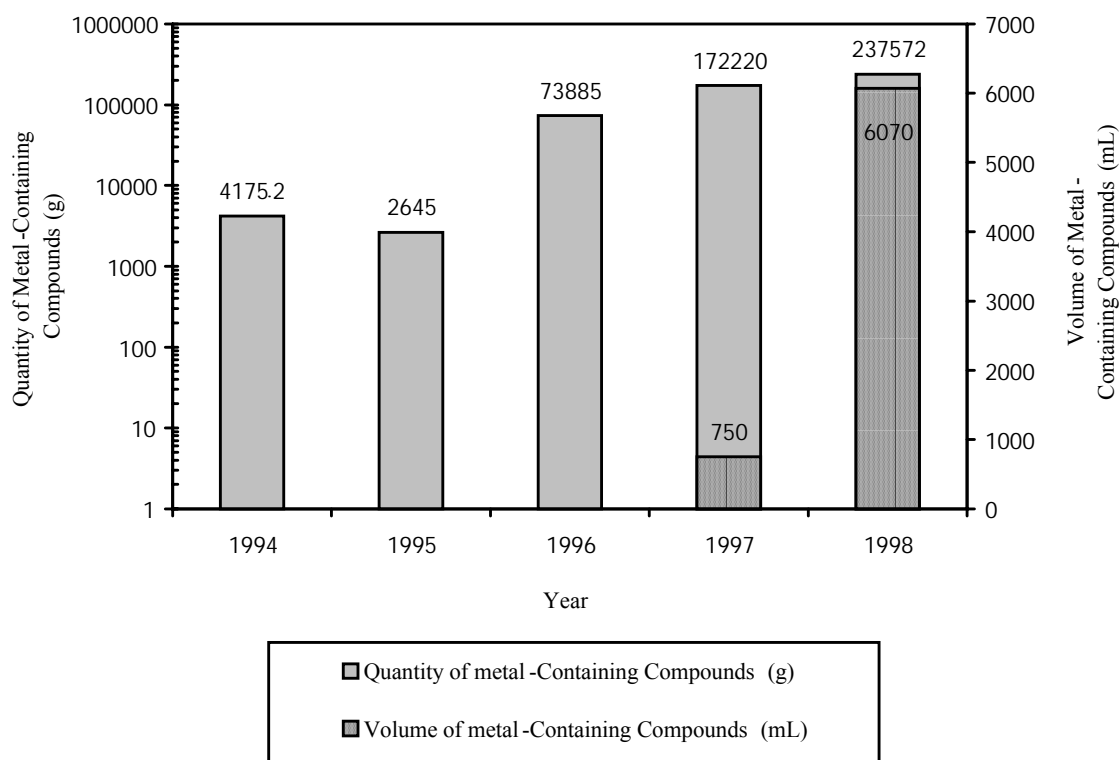


Figure 4-5. The metal-containing compounds used in the years 1994-1998.

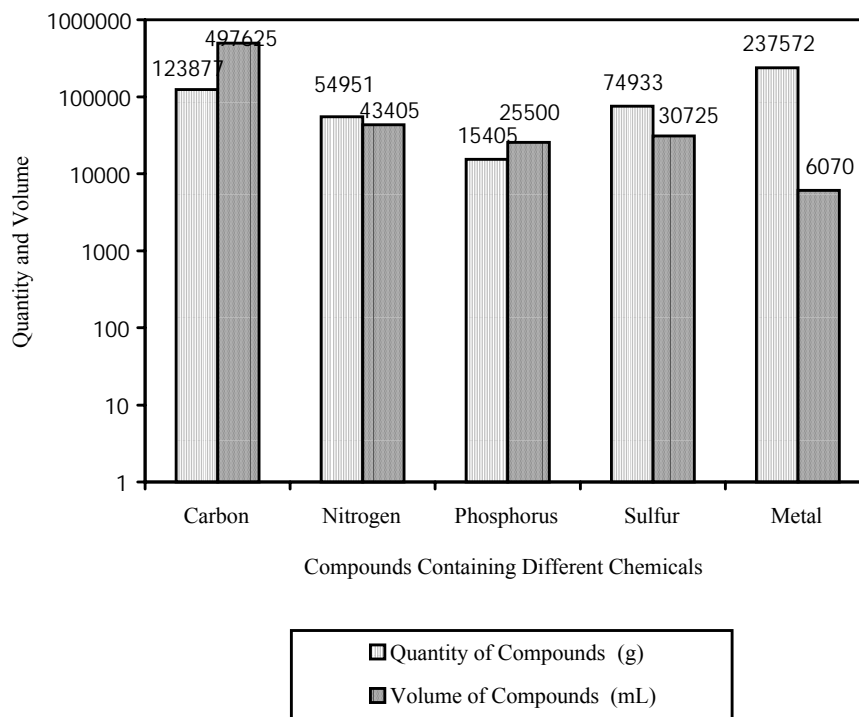


Figure 4-6. Quantity and volume of compounds containing different chemicals used in the year 1998.

Figures 4-7 to 4-11 show the relations between student numbers and amount of chemicals used during the years 1994-1998. It is found that the amount of chemicals used increased when the number of students increased. Carbon and sulfur-containing compounds were increased in exponential lines while student numbers were in straight lines as shown in Figures 4-7 and 4-10. At the same time, the quantities of nitrogen, phosphorus, and metal-containing compounds were increased rapidly in each year as illustrated in Figures 4-8, 4-9, and 4-11. In the year 1998, the quantities of carbon, nitrogen, phosphorus, sulfur, and metal containing compounds used were increased by 96.6%, 98.1%, 67.5%, 97.5%, and 98.2%, respectively, from the year 1994 while the number of students increased by 84.5%. Table 4-1 shows the quantity of chemical-containing compounds used per student in the year 1998.

Next, the relationship between the types of chemicals used and student levels was examined. There is no variation in types of chemicals used for undergraduate student and graduate students who are studying course work. On the other hand, types of chemicals used vary for graduate students who are doing their thesis work.

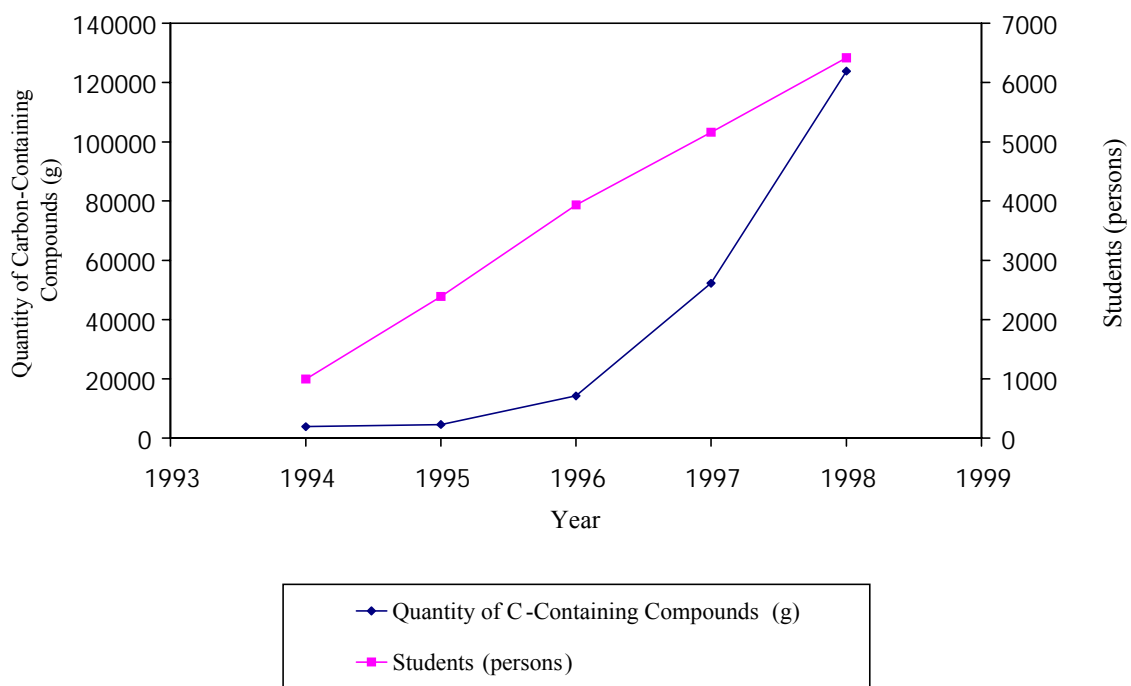


Figure 4-7. Quantity of carbon-containing compounds and students during the years 1994-1998.

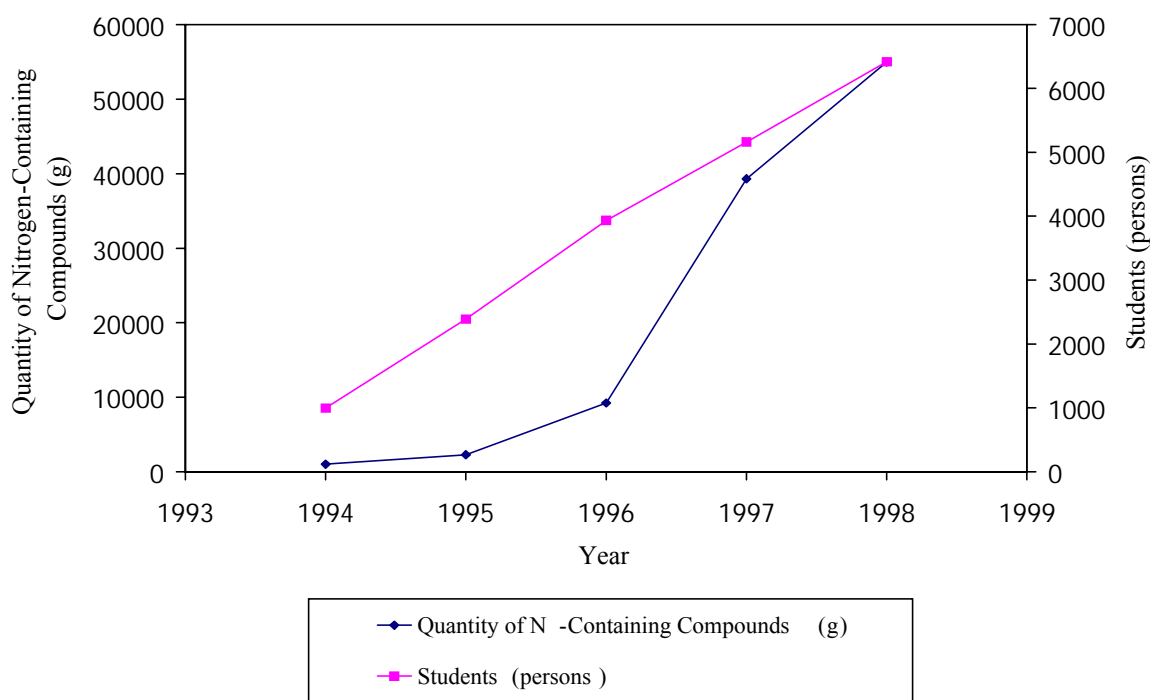


Figure 4-8. Quantity of nitrogen-containing compounds and students during the years 1994-1998.

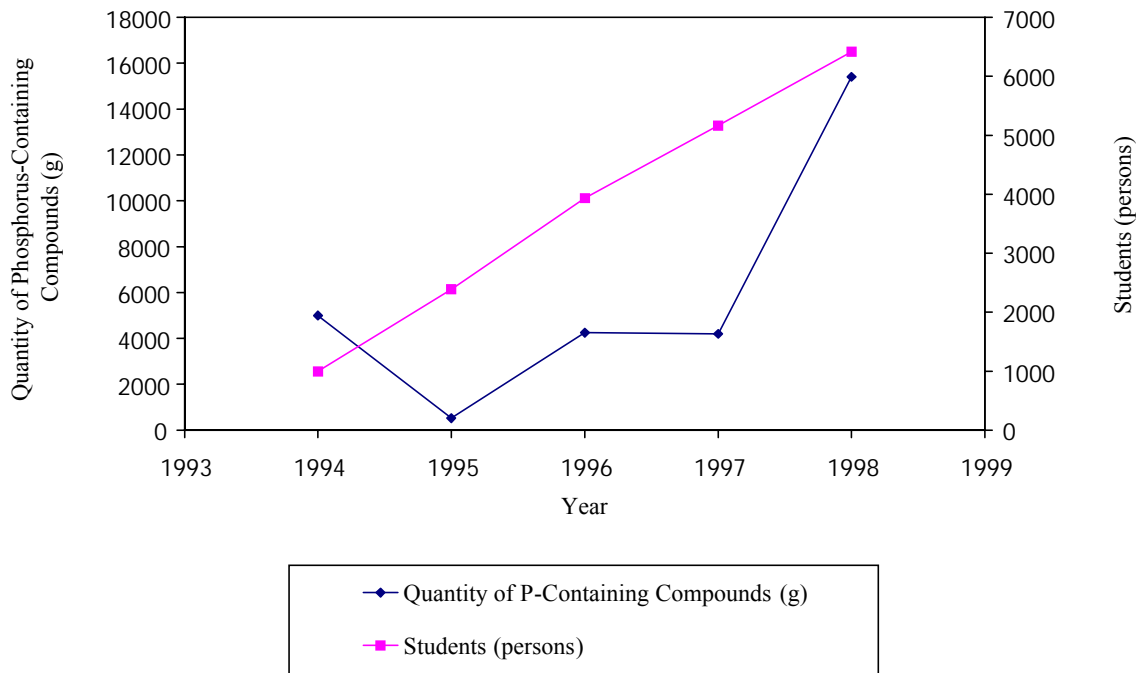


Figure 4-9. Quantity of phosphorus-containing compounds and students during the years 1994-1998.

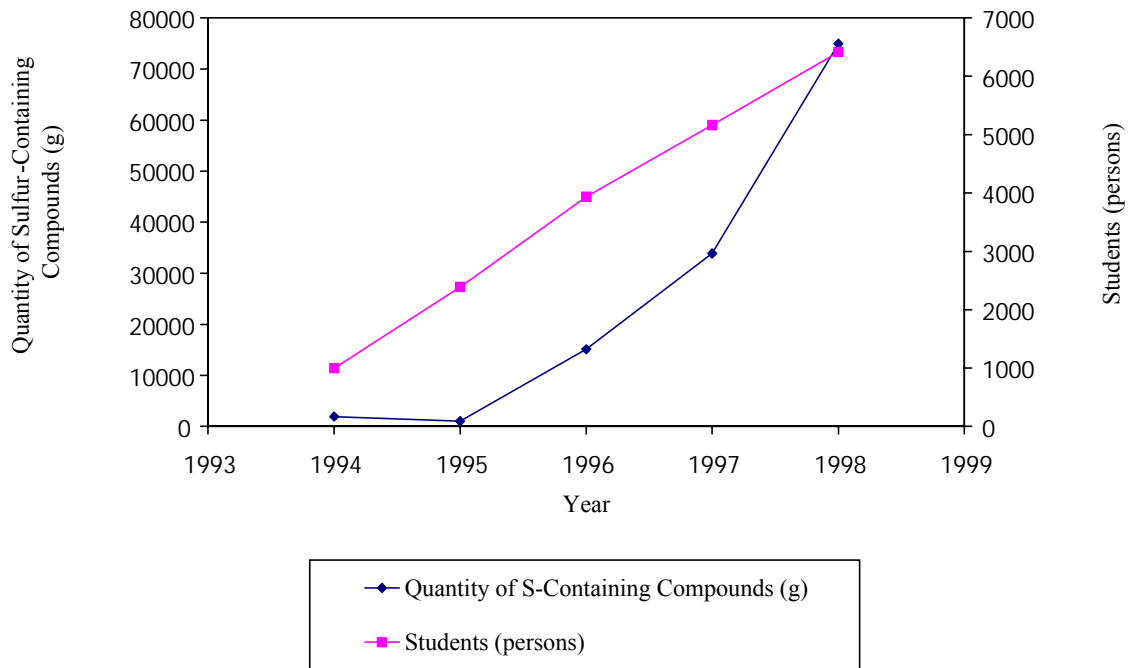


Figure 4-10. Quantity of sulfur-containing compounds and students during the years 1994-1998.

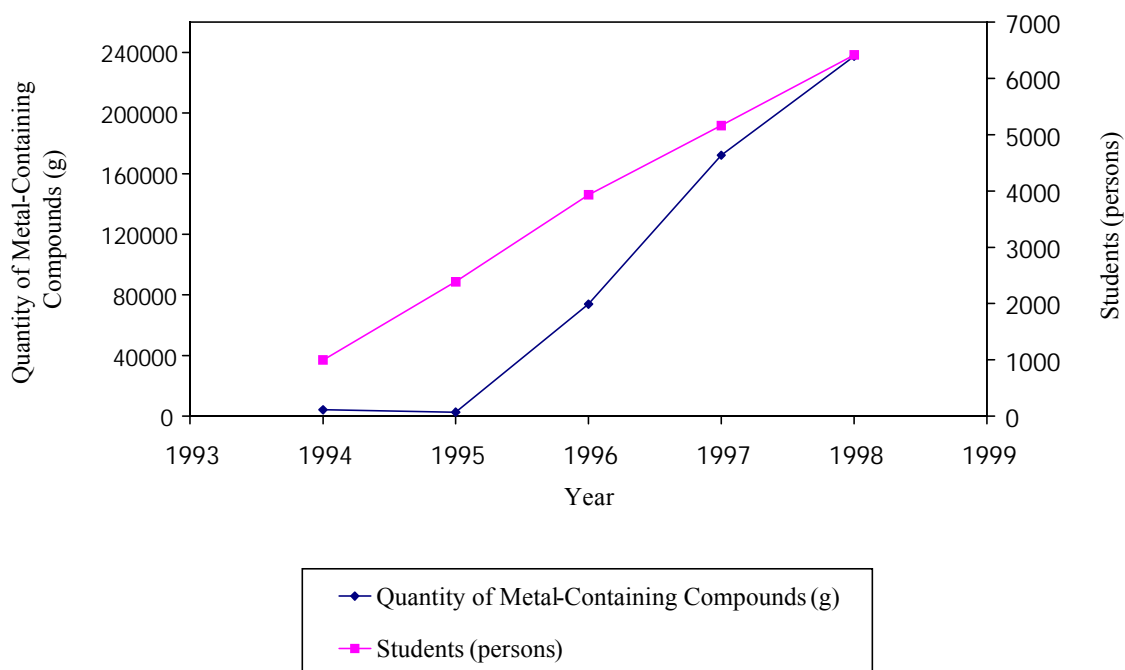


Figure 4-11. Quantity of metal-containing compounds and students during the years 1994-1998.

Table 4-1. The quantity of chemical-containing compounds used per student in the year 1998.

Classification of Chemical-Containing Compounds	Quantity of Chemical-Containing Compound (g) Used per Student (person)
Carbon	19.30
Nitrogen	8.56
Phosphorus	2.04
Sulfur	11.67
Metal	37.02

There are 19 schools for undergraduate students with chemical laboratory courses including:

1. crop production technology
2. animal production
3. food technology
4. agricultural engineering
5. ceramic engineering
6. chemical engineering
7. civil engineering
8. computer engineering
9. electrical engineering
10. environmental engineering
11. geotechnology
12. industrial engineering
13. mechanical engineering
14. metallurgical engineering
15. polymer engineering
16. telecommunication engineering
17. transportation engineering
18. occupational health and safety
19. environmental health

For graduate students in the schools, which have to use chemicals, the types of chemicals are fixed for normal laboratory work but vary when they are working in the laboratories for the thesis.

There are 15 schools for graduate students including:

1. crop production technology
2. animal production
3. food technology
4. biotechnology
5. chemistry
6. biochemistry

7. environmental biology
8. microbiology
9. chemical engineering
10. civil engineering
11. electrical engineering
12. environmental engineering
13. geotechnology
14. mechanical engineering
15. polymer engineering

Since wastewater from laboratories have a high variation in chemical and physical properties, selection of the suitable treatment method is very important. Results obtained from this study may help in such selection and lead to safe and economic treatments. This study also aims to find out suitable methods for wastewaters treatment as discussed in the next part. The good treatment process will play an important role in obtaining the appropriate and high efficiency waste treatment system.

4.2 Precipitation Experiments

4.2.1 The Effect of pH

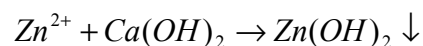
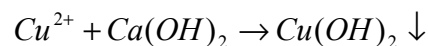
pH adjustment and control are necessary for effective coagulation and flocculation of Cu and Zn. Lime $[\text{Ca}(\text{OH})_2]$ is the most common base used to raise the pH, and hydrochloric $[\text{HCl}]$ acid to decrease pH. Table 4-2 shows the various pH, corresponding Cu and Zn residual concentrations, and the volume of lime and hydrochloric used to adjust pH. The synthetic wastewater initial pH was 6.9. In determining the optimum pH for Cu and Zn precipitation, the pH that produced flocs and low residual concentration, was chosen as the optimum coagulation pH. It was found that as the pH increased, Cu and Zn residual concentrations decreased. For pH more than 8, residual Cu concentration decreased approximately 0.1 ppm for an increase of 0.5 in pH. In case of Zn, for pH more than 8.5, Zn residual concentration decreased about 0.05 ppm for a increase of 0.5 in pH. Only little increase in Cu and Zn removal occurred at pH higher than 8. Cu and Zn removal by precipitation were

Table 4-2. Residual and % removal of Cu and Zn at pH 4-12.5.

pH	HCl (mL)	Ca(OH) ₂ (mL)	Cu Residual (ppm)	Zn Residual (ppm)	% Cu Removal	% Zn Removal
4.0	4.6	-	>15	>5	<62.50	<50.00
4.5	4.5	-	>15	>5	<62.50	<50.00
5.0	4.2	-	>15	>5	<62.50	<50.00
5.5	3.5	-	>15	>5	<62.50	<50.00
6.0	2.75	-	>15	>5	<62.50	<50.00
6.5	1.2		9.04	>5	77.40	<50.00
7.0	-	0.5	1.92	>5	95.20	<50.00
7.5	-	1.5	0.94	3.03	97.65	69.70
8.0	-	3	0.58	0.35	98.55	96.50
8.5	-	5	0.33	0.19	99.18	98.10
9.0	-	8	0.21	0.07	99.48	99.30
9.5	-	26	0.09	0.05	99.78	99.50
10.0	-	29	no detection*	0.02	-	99.80
10.5	-	42	no detection	0.02	-	99.80
11.0	-	60	no detection	0.02	-	99.80
11.5	-	92	0.06	0.01	99.85	99.90
12.0	-	170	no detection	0.01	-	99.90
12.5	-	208	0.04	0.01	99.90	99.90

* The concentration is below the limit of detection of the AAS.

very low for pH below 7 and 7.5, respectively. The Ca(OH)₂ dose required to adjust pH for high Cu and Zn removal, i.e. ≥ pH 8, is 3 mL or greater (Table 4-2). pH 8 was chosen as the optimum coagulation pH, since removal did not increase significantly for pH>8. Precipitate sludges that are formed when Cu and Zn react with Ca(OH)₂, are shown in following equations:



4.2.2 The Effect of Alum Concentration

Figure 4-12 shows the relationship between Cu and Zn residual concentrations and alum dosages over a range of 1-240 mg/L. The figure shows that better metal removal occurred when more dilute alum solution was added. Since all the variables, except the concentration of the alum solution, were held constant, the possibility of factors other than the alum dilution affecting the metal removal was eliminated. The more dilute alum solution, the less pH change and the better result. For example, 1 mg/L alum concentration removed Cu and Zn 97.73% and 90.70 %, respectively, and did not change the pH. On the other hand, 100-mg/L alum concentration removed only 93.75% of Cu and 75.70 % of Zn and decreased the pH to 7.15, as shown in Table 4-3. This outcome was obtained possibly because alum solution reacted with water to produce H_2SO_4 .

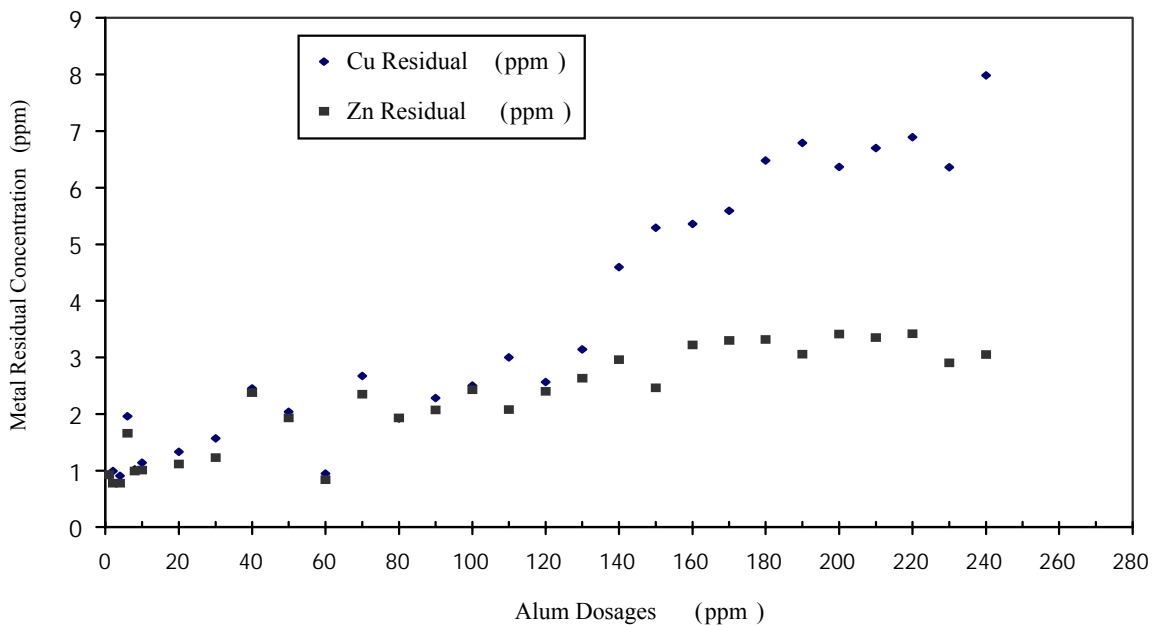


Figure 4-12. Cu and Zn residual concentrations at alum-solution concentration of 1-240 ppm.

Table 4-3. Residual and % removal of Cu and Zn at pH 8 for alum-solution concentration of 1-240 ppm.

Alum Dosages (ppm)	Supernatant pH	Cu Residual (ppm)	Zn Residual (ppm)	% Cu Removal	% Zn Removal
1	8.00	0.91	0.93	97.73	90.70
2	8.00	0.99	0.78	97.53	92.20
4	8.00	0.91	0.78	97.73	92.20
6	8.00	1.96	1.66	95.10	83.40
8	8.00	1.02	0.99	97.45	90.10
10	7.99	1.14	1.01	97.15	89.90
20	7.77	1.33	1.12	96.68	88.80
30	7.69	1.57	1.23	96.08	87.70
40	7.63	2.45	2.38	93.88	76.20
50	7.58	2.04	1.93	94.90	80.70
60	7.44	2.34	2.10	94.15	79.00
70	7.39	2.67	2.35	93.33	76.50
80	7.28	1.92	1.93	95.20	80.70
90	7.19	2.28	2.07	94.30	79.30
100	7.15	2.50	2.43	93.75	75.70
110	7.14	3.00	2.08	92.50	79.20
120	7.09	2.56	2.40	93.60	76.00
130	7.02	3.14	2.63	92.50	73.70
140	6.84	4.60	2.96	88.50	70.40
150	6.78	5.29	2.46	86.78	75.40
160	6.74	5.36	3.22	86.60	67.80
170	6.72	5.59	3.30	86.03	67.00
180	6.62	6.48	3.32	83.80	66.80
190	6.60	6.79	3.06	83.00	69.40
200	6.82	6.37	3.41	84.08	65.90
210	6.88	6.70	3.35	83.25	66.50
220	6.86	6.89	3.42	82.78	65.80
230	6.83	6.36	2.90	84.10	71.00
240	6.80	7.98	3.05	80.05	69.50

The use of aluminium sulphate concentration over a range of 1-240 ppm resulted in the supernatant pH of 6.8-8. When aluminium sulphate concentration was increased the pH was decreased, because aluminium sulphate was hydrolyzed by water. When the concentration at 1 ppm of aluminium sulphate was used, the best metals removal was obtained. This trend suggested that one employ lower coagulant additions for more efficient metals removal. To provide sufficient nucleating sites, lime has to be added to maintain the coagulation/flocculation pH close to 8. As the

pH was raised further, aluminium hydrolysis of both complexed and unbound excess aluminium occurred. Hydrolysis of complexed aluminium led to the formation of metals where the hydroxide ions could bond and result in further precipitation. Excess aluminium hydrolyses and forms heterogeneous flocs with the precipitated complex. Homogeneous floc formation entrapment would be minimal because the pH and concentration of aluminium are much lower than required for rapid precipitation sweep coagulation. By this mechanism, precipitation will occur as a consequence of size rather than charge-neutrality.

4.2.3 The Effect of Ferric Chloride

Figure 4-13 shows the relationship between metal residual concentration and ferric chloride dosages over a range of 0.2-26 ppm. Table 4-4 shows the various dosages of ferric chloride used and the residual metals. It was found that as the ferric chloride dosage was increased, residual metals were increased. The amounts of ferric chloride used were determined by trial-and-error method so that the resulting residual metals concentrations were within ± 0.01 ppm as indicated in Table 4-4. Very little increase in Cu and Zn removal occurred beyond a ferric chloride dosage of 0.2 ppm. Therefore, 0.2 ppm was chosen as the optimum dosage of ferric chloride. Increasing ferric chloride concentration resulted in lower removal of Cu and Zn than did decreasing ferric chloride concentration, as low turbidity synthetic wastewater not provides a ready source of nucleating sites for floc development. This situation was occurred the same for alum coagulant adding after lime.

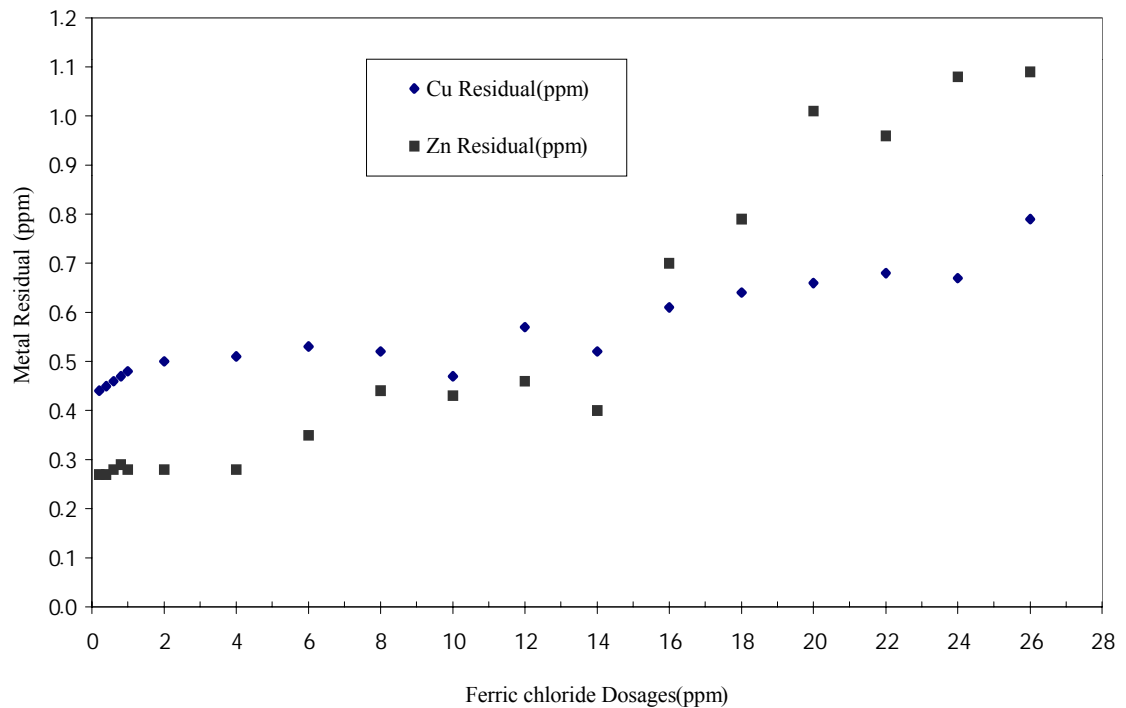


Figure 4-13. Cu and Zn residual after precipitation and ferric chloride dosages.

Table 4-4. Residual and % removal of Cu and Zn at pH 8 for ferric chloride-solution of 0.2-26 ppm.

Ferric chloride (ppm)	Supernatant pH	Cu Residual (ppm)	Zn Residual (ppm)	% Cu Removal	% Zn Removal
0.2	8.00	0.44	0.27	98.90	97.30
0.4	8.00	0.45	0.27	98.88	97.30
0.6	8.00	0.46	0.28	98.85	97.20
0.8	8.00	0.46	0.29	98.85	97.10
1	8.00	0.47	0.28	98.83	97.20
2	8.00	0.50	0.28	98.75	97.20
4	8.00	0.51	0.28	98.73	97.20
6	8.00	0.53	0.35	98.68	96.50
8	8.00	0.52	0.44	98.70	95.60
10	8.00	0.47	0.43	98.83	95.70
12	7.98	0.57	0.46	98.58	95.40
14	7.95	0.52	0.40	98.70	96.00
16	7.88	0.61	0.70	98.48	93.00
18	7.84	0.64	0.79	98.40	92.10
20	7.78	0.66	1.01	98.35	89.90
22	7.76	0.68	0.96	98.30	90.40
24	7.73	0.67	1.08	98.33	89.20
26	7.68	0.79	1.09	98.03	89.10

4.3 Adsorption Experiments

4.3.1 Acetic acid and Ethyl acetate Adsorption Isotherms

Adsorption isotherm constants for acetic acid and ethyl acetate are shown in Table 4-5 and Figures 4-14.

Table 4-5. Freundlich isotherm equation constants.

sorbate	Freundlich equation	
	$\log K_f$	$1/n$
Acetic acid	-2.00	1.27
Ethyl acetate	-1.14	1.25

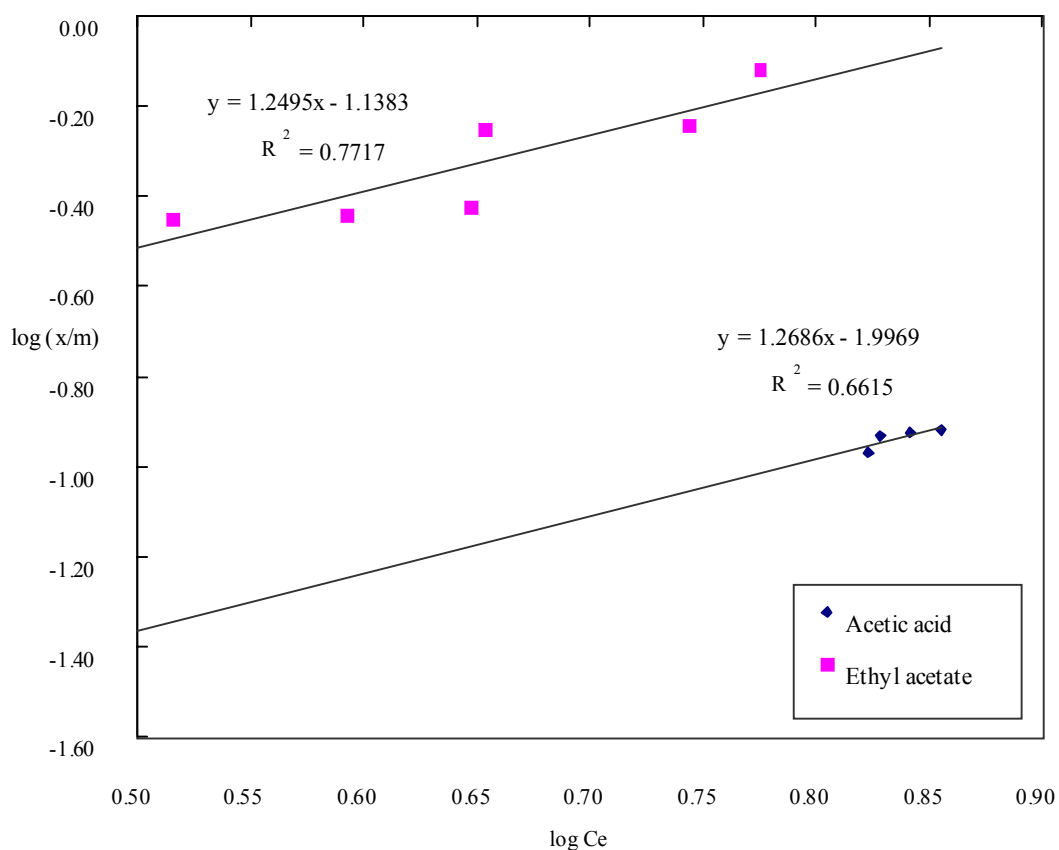


Figure 4-14. Freundlich plots of adsorption isotherm.

The carbon capacities for the adsorption of acetic acid and ethyl acetate from their pure solutions were observed to be similar, as may be seen in Figures 4-14. It shows that the adsorption capacity for acetic acid was considerably lower than that for ethyl acetate at high equilibrium concentration. The fact that ethyl acetate was adsorbed better than acetic acid at high equilibrium concentration indicated that ethyl acetate had a higher affinity for the carbon than acetic acid. It should be noted that acetic acid is more water-soluble than ethyl acetate, so that one might have expected the more hydrophobic ethyl acetate to be more susceptible to adsorption. If compounds are assumed to be adsorbed on the carbon surface with the same face-on orientation, then the higher affinity of the more molecular weight of compounds for the carbon may be explained by their large plane area in contact with the carbon surface, van der Waals forces (the main forces in physical adsorption) being stronger the larger the surface they are acting upon.

The slow approach to equilibrium as well as the existence of a unique isotherm were well established by the experimental results. This slow approach to equilibrium is illustrated in Figure 4-15. This Figure uses data from Table B-15 of Appendix B, which is obtained from the batch kinetic experiments with ethyl acetate. The curve shows that about 58% of the capacity is utilized in the first one day, and the subsequent approach to equilibrium is gradual. For this system, the change in concentration between the third and fourth days was less than 1 g/L, as indicated in Table B-15, and therefore such change may not be observed because it is within the experimental error of many measurement techniques (Peel and Benedek, 1980).

The phenomena noted above demonstrate some underlying problems in typical techniques for evaluating isotherms. In this experiment work, the approach is valid since the test period is long enough. In certain cases, however, equilibrium is assumed to have been reached when no further changes in concentration are observed. As the above analysis shows, slight errors in concentration measurement, carbon masses weighing, or just in allowing insufficient time between evaluations could lead to the incorrect assumption that equilibrium had been reached. Isotherms evaluated in

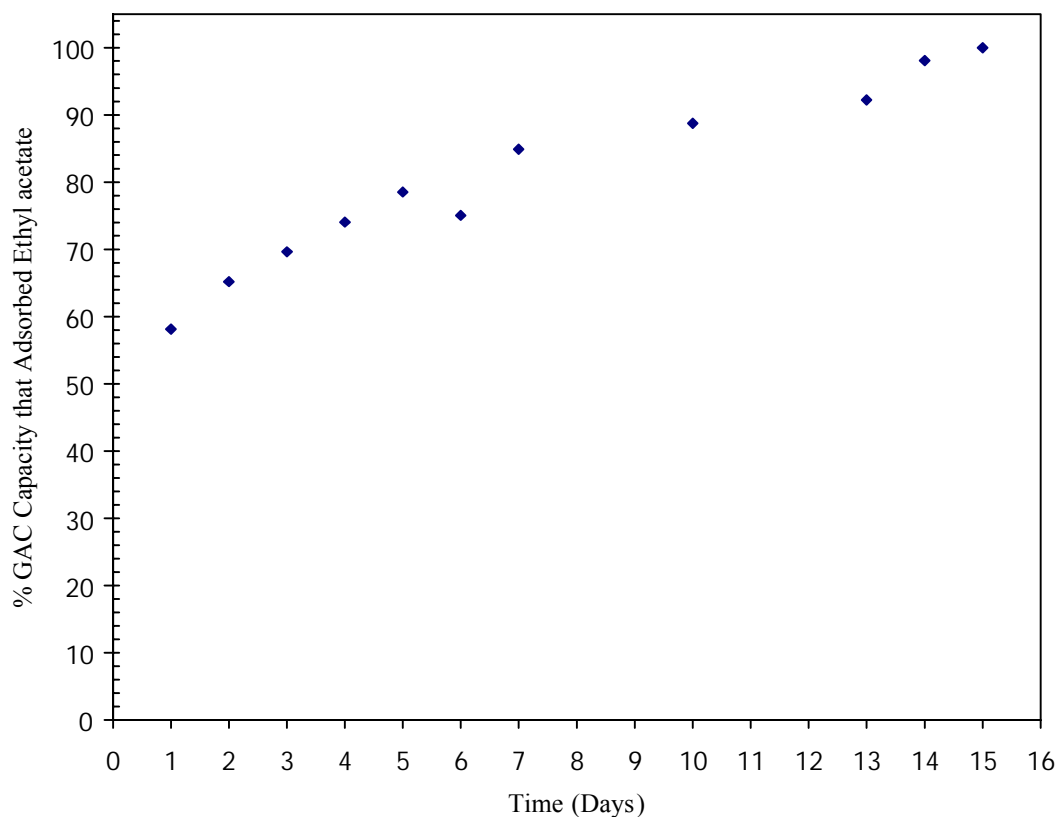


Figure 4-15. Batch kinetics data plotted over 15 days of ethyl acetate.

such fashion may not be at true equilibrium, and would give a lower apparent capacity than that which would be obtained in a full-term experiment. The isotherm which only account for fraction of the capacity utilized in the initial rapid adsorption period is called “pseudo”-isotherm (Peel and Benedesk, 1980). A similar problem lies in using short rapid flow columns to evaluate adsorption capacities. If the time span of experiment is not long enough to include the slow uptake capacity, the results will not be applicable for larger systems operated for much longer time spans in which the slow uptake capacity is more fully realized.

4.3.2 Fixed-Bed Adsorption Columns Experiments

The size of the column used in the experiment was 7.5-cm in diameter and 25-cm in height. It was filled with 400 g of granular activated coconut shell-based

carbon with particle size 0.60-2.36 mm, which was used as adsorbent in adsorption experiment.

The breakthrough curve was obtained by plotting effluent of two adsorbates concentration versus volume (mL) of water treated as shown in Figure 4-16.

Investigation the adsorption of with acetic acid and ethyl acetate were initially conducted with concentration of 0.14 and 0.10 moles/L, respectively. The initial pH were 3.16 for acetic acid and 4.20 for ethyl acetate. In this experiment, the breakthrough for acetic acid was achieved after approximately 1,000 mL of synthetic wastewater were added, and about 9,000 mL synthetic wastewater for the breakthrough of ethyl acetate to occur.

4.4 Design Example

To illustrate the use of the results obtained from this study, the design examples are given as follows.

4.4.1 Design Example of Precipitation Process

Problem

The wastewater with a pH of 7.15 and a total alkalinity of 275 mg/L as CaCO_3 requires a dose of 0.2 mg/L ferric chloride [$\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$] for effective coagulation/flocculation. From the experiment, the optimum pH is 8 for precipitation of Cu and Zn, and total alkalinity of 302 mg/L as CaCO_3 . What is the dose of $\text{Ca}(\text{OH})_2$ in mg/L as CaCO_3 required to maintain the total alkalinity of 302 mg/L as CaCO_3 during coagulation/flocculation? The quantity of wastewater to be treated is 20 m³/d. Make a simplifying assumption that the only hydroxoferric (III) species to form is $\text{Fe}(\text{OH})_3$; this assumption is valid at many surface wastewater treatment plants.

Solution

This problem can be treated as a stoichiometric acid/base reaction. Since the alkalinity for the reaction will come entirely from the $\text{Ca}(\text{OH})_2$ to be added, it was used as the base in the reaction.

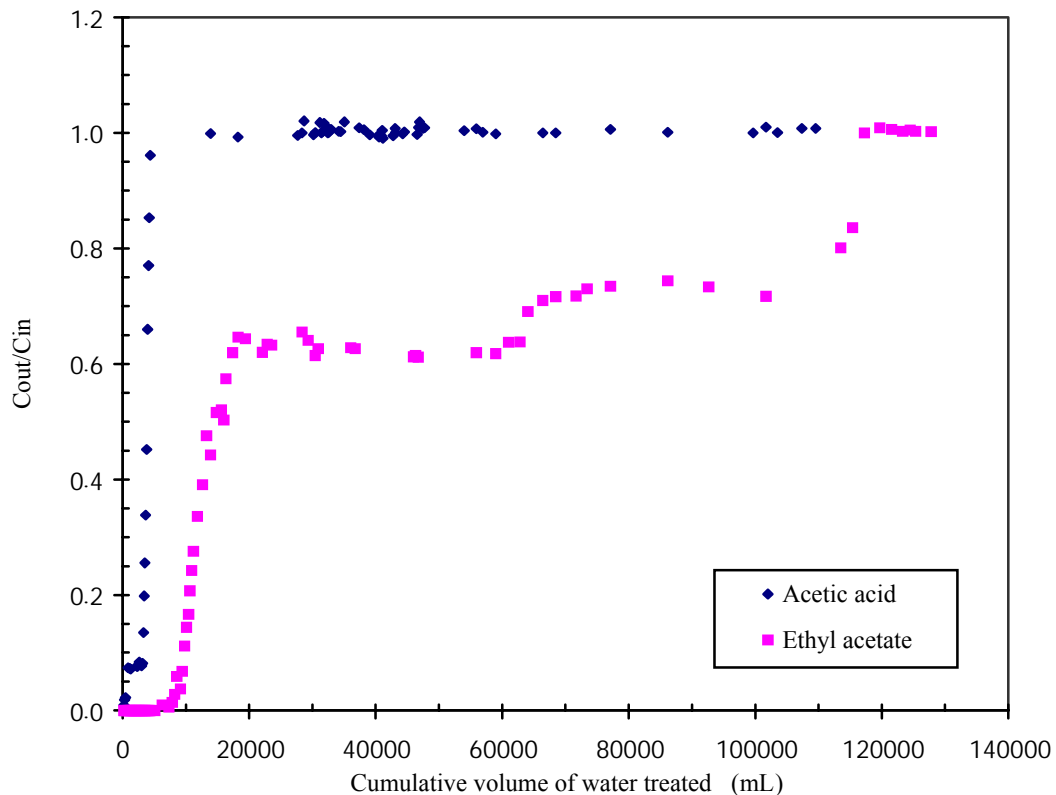
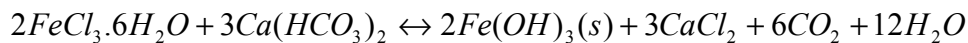


Figure 4-16. Carbon adsorption breakthrough curve of acetic acid and ethyl acetate.



The molecular weight of ferric chloride [$\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$] is 270.35 and that of lime [$\text{Ca}(\text{HCO}_3)_2$] is 162. Determine the solution concentration of $\text{Ca}(\text{HCO}_3)_2$ required, when a dose of $\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$ equal to 0.2 mg/L.

$$\frac{(\text{FeCl}_3 \cdot 6\text{H}_2\text{O} \text{ concentration})}{(\text{mole} * \text{molecular weight})_{\text{FeCl}_3 \cdot 6\text{H}_2\text{O}}} * (\text{mole} * \text{molecular weight})_{\text{Ca}(\text{HCO}_3)_2} =$$

$$\frac{\left(0.2 \frac{\text{mg}}{\text{L}}\right)}{\left(2 * 270.35 \frac{\text{g}}{\text{moles}}\right)} * \left(3 * 162 \frac{\text{g}}{\text{moles}}\right) = 0.18 \text{ mg/L}$$

$$\text{is required, or } \left(0.18 \frac{\text{mg}}{\text{L}}\right) \left(\frac{50 \frac{\text{g}}{\text{eq}}}{81 \frac{\text{g}}{\text{eq}}}\right) + \left(27 \frac{\text{mg as CaCO}_3}{\text{L}}\right) = 27.11 \frac{\text{mg as CaCO}_3}{\text{L}}$$

$$\left(27.11 \frac{\text{mg as CaCO}_3}{\text{L}}\right) \left(20 \frac{\text{m}^3}{\text{d}}\right) \left(\frac{1000 \text{ L}}{\text{m}^3}\right) = 542.20 \frac{\text{g as CaCO}_3}{\text{d}}$$

4.4.2 Design Example of Fixed-Bed Column

Prior to the example discussion, a review of the kinetic approach for designing a fixed bed column is presented as follow.

Kinetic approach is one of the approach used to design fixed bed column. This method utilizes a kinetic equation based on the derivation by Thomas (1948). The kinetic equation may also be derived from an extension of the Bohart and Adam (1920) equation (Loebenstein, 1975). The principal experimental information required is a breakthrough curve from a test column, either laboratory or pilot scale (Reynolds and Richard, 1996).

The expression Thomas for an adsorption column is as follows:

$$\frac{C}{C_0} = \frac{1}{1 + e^{\frac{k_1(q_0M - C_0V)}{Q}}} \quad (4-1)$$

where

C = effluent solute concentration-for example, g/L

C_0 = influent solute concentration-for example, g/L

k_1 = rate constant-for example-for example, L/s-kg

q_0 = maximum solid-phase concentration of the sorbed solute-for example, gm per gm

M = mass of the adsorbent-for example, gm

V = throughput volume-for example, liters

Q = flow rate-for example, liters per hour

Assuming the left side equals the right side, cross multiplying gives

$$1 + e^{\frac{k_1(q_0M - C_0V)}{Q}} = \frac{C_0}{C} \quad (4-2)$$

Rearranging and taking the natural logarithms of both sides yield the design equation

$$\ln\left(\frac{C_0}{C} - 1\right) = \frac{k_1q_0M}{Q} - \frac{k_1C_0V}{Q} \quad (4-3)$$

From equation (4-3), it can be seen that this is a straight-line equation of the type $y=ax+b$. The terms are $y = \ln\left(\frac{C_0}{C} - 1\right)$, $x = V$, $m = k_1 C_0 / Q$, and $b = k_1 q_0 M / Q$.

The laboratory-or pilot-scale column used to obtain the breakthrough curve for the kinetic design approach should be operated at approximately the same flowrate in terms of bed volumes per hour as the design column. One advantage of the kinetic approach is that the breakthrough volume, V , may be selected in the design of a column.

Problem

Ethyl acetate wastewater having concentration 8.99 g/L is to be treated by a fixed-bed granular carbon adsorption column for a wastewater flow of 20 m³/d, and the allowable effluent concentration, is 0.45 g/L. The design column is to have a unit liquid flowrate of 0.50 L/s-m². The data concerning the laboratory column are as follows: inside diameter = 7.50 cm, length = 25 cm, mass of carbon = 400 g, liquid flowrate = 16.66 mL/min, packed carbon density = 540 kg/m³. The design column is to have a unit liquid flowrate = 0.50 L/s-m², and allowable breakthrough volume is 100 m³. The partial data for the portion of the curve where breakthrough occurs are given in Table 4-6. Using the kinetic approach for design, determine:

- (1) The design reaction constant, k_1 , L/s-kg
- (2) The design maximum solid-phase concentration, q_0 , kg/kg
- (3) The carbon required for the design column, kg
- (4) The diameter and height of the design column, m
- (5) The kilograms of carbon required per cubic meter of waste treated, kg/m³

Solution

The plot of $\ln\left(\frac{C_0}{C} - 1\right)$ versus V is shown in Figure 4-17, the slope = $k_1 C_0 / Q$

or 0.46 L⁻¹. The value of

$$k_1 = (\text{slope}) \left(Q / C_0 \right) \text{ or } k_1 = \left(0.46 \text{ L}^{-1} \right) \left(1.0 \frac{\text{L}}{\text{h}} \right) \left(\text{h} / 3600 \text{ s} \right) \left(\text{L} / 8.99 \text{ g} \right) \left(1000 \text{ g} / \text{kg} \right)$$

$$k_1 = 1.42 \times 10^{-2} \text{ L/s-kg} .$$

The y-axis intercept, b , equal 6.59. Since

$$b = k_1 q_0 M / Q k_1, \text{ rearranging gives}$$

$$q_0 = bQ / k_1 M = (6.59) (1.0 \text{ L/h}) (s - \text{kg} / 1.42 * 10^{-2} \text{ L}) (h / 3600 \text{ s}) (1 / 0.4 \text{ kg}) = 0.32 \text{ kg/kg}.$$

The mass of carbon, M , may be computed from Eq (4-3), which is

$$\ln\left(\frac{C_0}{C} - 1\right) = \frac{k_1 q_0 M}{Q} - \frac{k_1 C_0 V}{Q}$$

$$\ln\left(\frac{8.99}{0.45} - 1\right) = \left(\frac{1.42 * 10^{-2} \text{ L}}{s - \text{kg}}\right) \left(\frac{0.32 \text{ kg}}{\text{kg}}\right) \left(\frac{d}{20 \text{ m}^3}\right) \left(\frac{86400 \text{ s}}{d}\right) \left(\frac{\text{m}^3}{1000 \text{ L}}\right) (M \text{ kg})$$

$$- \left(\frac{1.42 * 10^{-2} \text{ L}}{s - \text{kg}}\right) \left(\frac{8.99 \text{ g}}{\text{L}}\right) \left(\frac{d}{20 \text{ m}^3}\right) 100 \text{ m}^3 \left(\frac{86400 \text{ s}}{d}\right) \left(\frac{1 \text{ kg}}{1000 \text{ g}}\right)$$

From this $M = 2963.69 \text{ kg}$. The column diameter is

$$D = \left[\left((20 \text{ m}^3 / d) d / 86400 \text{ s} (s - \text{m}^2 / 0.5 \text{ L}) (1000 \text{ L} / \text{m}^3) (4 / \pi) \right)^{1/2} \right] = 0.77 \text{ m}.$$

$$\text{Volume} = (2963.69 \text{ kg}) (1 \text{ m}^3 / 540 \text{ kg}) = 5.49 \text{ m}^3.$$

$$\text{The carbon height is } Z = (5.49 \text{ m}^3) (4 / \pi) (1 / 0.77 \text{ m})^2 = 11.77 \text{ m}.$$

$$\text{The carbon required is } \left(\frac{2963.69 \text{ kg}}{100 \text{ m}^3} \right) = 29.64 \text{ kg/m}^3.$$

The carbon required by the kinetic approach is 2963.69 kg.

Table 4-6. Partial data from breakthrough test.

(1) V (L)	(2) C (g/L)	(3) C/C ₀	(4) C ₀ /C	(5) ln [(C ₀ /C)-1]
8.24	0.25	0.03	36.09	3.56
9.13	0.34	0.04	26.72	3.25
9.43	0.61	0.07	14.71	2.62
9.79	1.00	0.11	8.99	2.08
10.11	1.29	0.14	6.97	1.79
10.41	1.49	0.17	6.02	1.61
10.67	1.86	0.21	4.83	1.34
10.94	2.18	0.24	4.13	1.14
11.20	2.48	0.28	3.63	0.97
11.85	3.02	0.34	2.98	0.68
12.61	3.51	0.39	2.56	0.45
13.29	4.27	0.47	2.11	0.10
14.80	4.63	0.52	1.94	-0.06
15.64	4.68	0.52	1.92	-0.08
16.33	5.16	0.57	1.74	-0.30

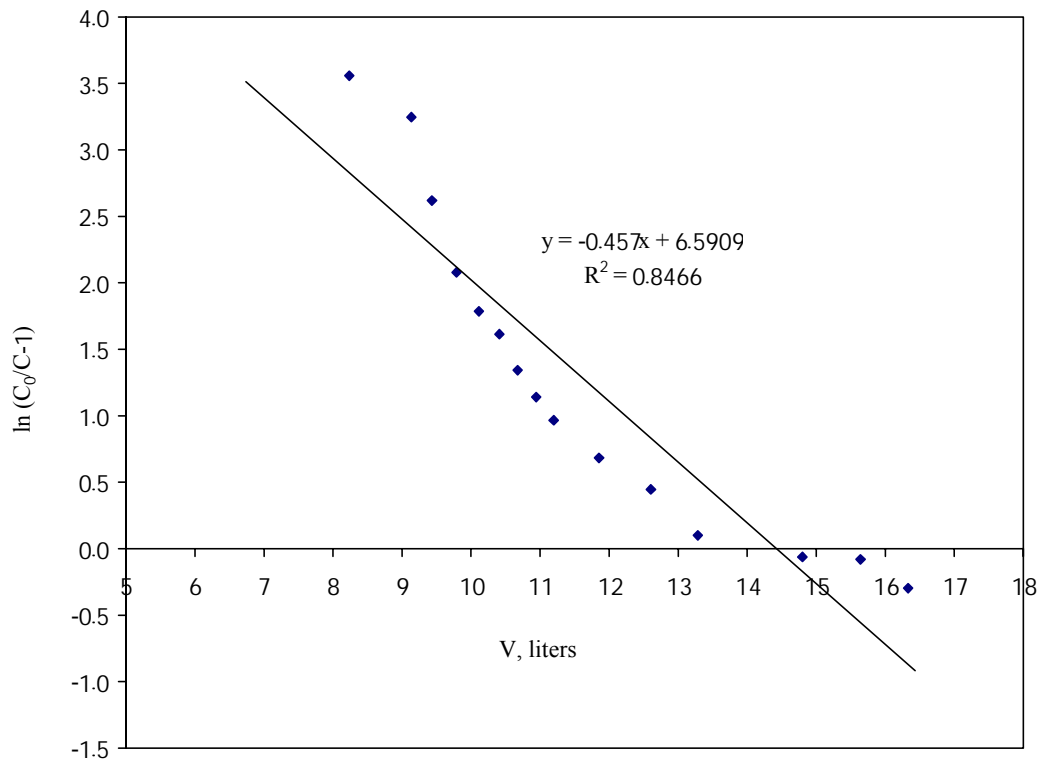


Figure 4-17. Plot of fixed-bed column design example of ethyl acetate.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

From the experimental investigation, the following conclusions can be drawn.

(1) Chemicals used in SUT were categorized into 5 different groups. The great variety of chemicals generated requires appropriate handling. The inventory of chemical composition and amount can be used by the treatment facility to plan appropriate waste treatment and management scheme.

(2) The optimum coagulation pH for Cu and Zn removal with minimum Ca(OH)_2 addition was found to be 8. Relying on Cu and Zn removal alone, as the indicator, would have resulted in an optimum pH at 10. The Cu and Zn residual in the treated wastewater decreased as the Ca(OH)_2 dose increased. Underdosing of Ca(OH)_2 is clearly more of a concern than overdosing in terms of residual Cu and Zn. Overdosing results in no significant increase in Cu and Zn removal. In contrast, for doses lower than the optimum value (for this synthetic wastewater, lower than 30 mg/mL as CaCO_3), the percent of Cu and Zn removal decreased.

(3) The use of alum or ferric chloride after lime addition did not result in any improvement of Cu and Zn removal efficiency. Furthermore, both coagulants decrease the pH of the wastewater and hence create pH levels that are not appropriate for metal removal.

(4) In adsorption experiments using coconut shell based granular activated carbon of size 0.20-26.0 mm, the results indicated that ethyl acetate was adsorbed better than acetic acid because the former has higher molecular weight and therefore higher affinity to the carbon surface. In addition, the surface characteristic of ethyl acetate is hydrophobic; thus, it is adsorbed on GAC better than the acetic acid, as shown in the Freundlich isotherm equation constants in Table 4-5.

(5) A slow, long-term activated carbon adsorption of ethyl acetate and acetic acid compounds have been demonstrated experimentally. Approximately 20-50% and 70-75% of the ultimate capacity was utilized within a few days in the case of ethyl acetate and acetic acid, respectively. The remaining capacity, however, took several days to be exhausted.

(6) The results of fixed-bed adsorption columns test revealed that acetic acid and ethyl acetate with concentrations of 0.14 and 0.10 moles/L, respectively, could pass the column for approximately 1,000 and 9,000 mL, respectively before reaching their breakthrough concentrations. The kinetics obtained from this test can be used to design the adsorption process with GAC for wastewater treatment in future.

5.2 Recommendations

The following may be carried out for further study:

- (1) Different criteria may be used to create a chemical inventory for SUT, i.e. using classification by treatment method.
- (2) The order of addition of lime and coagulants may be studied.
- (3) Based on this study's results, similar research can be carried out for other chemical substances used in the SUT laboratories.

APPENDIX A

**Inventory and Classification of Chemicals that Used in SUT
Laboratories in the Years 1994-1998**

Table A-1. Chemical substances used in SUT laboratories in year 1994.

Chemical substances category	Formula	Quantity
Carbon Compounds		
4-Methylaminophenol sulphae	$(\text{CH}_3\text{NHC}_6\text{H}_4\text{OH})_2 \cdot \text{H}_2\text{SO}_4$	1 lb
4-Dimethylaminobenzaldehyde	$(\text{CH}_3)_2\text{NC}_6\text{H}_4\text{CHO}$	1*100 g
Hydrocarbon	HC	1 lb
Potassium thiocyanate	KSCN	1 lb
Sodium carbonate anhydrous	Na_2CO_3	5 lb
Tetrapropylenebenzenesulphonic acid sodium salt	$(\text{CH}_3)_2\text{CH}(\text{CH}_2\text{CHCH}_3)_3 \cdot \text{C}_6\text{H}_4 \cdot \text{SO}_3\text{Na}$	
Trichloacetic acid	CCl_3COOH	1*100 g
Nitrogen Compounds		
4-Methylaminophenol sulphate	$(\text{CH}_3\text{NHC}_6\text{H}_4\text{OH})_2 \cdot \text{H}_2\text{SO}_4$	1 lb
4-Dimethylaminobenzaldehyde	$(\text{CH}_3)_2\text{NC}_6\text{H}_4\text{CHO}$	1*100 g
Potassium thiocyanate	KSCN	1 lb
Phosphorus Compounds		
Hypophosphorous acid	H_3PO_2	5 *1,000 g
Sulfur Compounds		
4-Methylaminophenol sulphae	$(\text{CH}_3\text{NHC}_6\text{H}_4\text{OH})_2 \cdot \text{H}_2\text{SO}_4$	1 lb
Potassium thiocyanate	KSCN	1 lb
Sulphuric acid 96%	H_2SO_4	1 *1,000 g
Tetrapropylenebenzenesulphonic acid sodium salt	$(\text{CH}_3)_2\text{CH}(\text{CH}_2\text{CHCH}_3)_3 \cdot \text{C}_6\text{H}_4 \cdot \text{SO}_3\text{Na}$	
Metals Compounds		
Potassium chromate	K_2CrO_4	1 *1,000 g
Potassium thiocyanate	KSCN	1 lb
Sodium carbonate anhydrous	Na_2CO_3	5 lb
Sodium tetraborate decahydrate	$\text{Na}_2\text{B}_4\text{O}_7 \cdot 10\text{H}_2\text{O}$	1 lb
Tetrapropylenebenzenesulphonic acid sodium salt	$(\text{CH}_3)_2\text{CH}(\text{CH}_2\text{CHCH}_3)_3 \cdot \text{C}_6\text{H}_4 \cdot \text{SO}_3\text{Na}$	

Table A-2. Chemical substances used in SUT laboratories in year 1995.

Chemical substances category	Formula	Quantity
Carbon Compounds		
Acetonitrile	CH_3CN	2*2,500 mL
2,6-Dichlorophenolindophenol sodium salt	$\text{NaOC}_6\text{H}_4 \cdot \text{C}_6\text{H}_2(\text{Cl}_2) \cdot \text{O} \cdot 2\text{H}_2\text{O}$	1*10 g
N-(2-Hydroxyethyl)morpholine	$\text{CH}_2(\text{CH}_2)_4\text{NCH}_2\text{CH}_2\text{OH}$	1*100 g
Anthrone	$\text{C}_6\text{H}_4\text{COC}_6\text{H}_4\text{CH}_2$	1*25 g
D(+)-Glucose anhydrous	$\text{CH}_2\text{OHCH}(\text{CHOH})_3\text{CHOH}$	1*100 g
Chloramine T	$\text{CH}_3\text{CH}_6\text{H}_4\text{SO}_2\text{NCINa} \cdot 3\text{H}_2\text{O}$	
Chloroacetic acid	CH_2ClCOOH	1 *1,000 g
Coomassie Brilliant Blue R 250	$\text{C}_{45}\text{H}_{44}\text{N}_3\text{NaO}_7\text{S}_2$	35 g
Dextros	$\text{CH}_2\text{OHCH}(\text{CHOH})_3\text{CHOH}$	1*500 g
4-Diamethylaminobenzaldehyde	$(\text{CH}_3)_2\text{NC}_6\text{H}_4\text{CHO}$	2*100 g
DL-Valine	$(\text{CH}_3)_2\text{CHCH}(\text{NH}_2)\text{COOH}$	1*100 g
Ethyl acetate	$\text{CH}_3\text{COOC}_2\text{H}_5$	1*2,500 mL
Lactose	$\text{C}_{12}\text{H}_{22}\text{O}_{11} \cdot \text{H}_2\text{O}$	500 g

Table A-2. (continued) Chemical substances used in SUT laboratories in year1995.

Chemical substances category	Formula	Quantity
Carbon Compounds		
Ethyl acetate	$\text{CH}_3\text{COOC}_2\text{H}_5$	1*2,500 mL
Lactose	$\text{C}_{12}\text{H}_{22}\text{O}_{11} \cdot \text{H}_2\text{O}$	500 g
L-proline	$\text{NH}(\text{CH}_2)\text{CHCOOH}$	1*100 g
N-Acetylglycine	$\text{CH}_3\text{CONHCH}_2\text{COOH}$	2*5 g
Ninhydrin	$\text{C}_6\text{H}_4\text{COCOCO} \cdot \text{H}_2\text{O}$	1*25 g
Nitrobenzene	$\text{C}_6\text{H}_5\text{NO}_2$	1*2,500 mL
p-Nitrophenylhydrazine	$\text{NO}_2\text{C}_6\text{H}_4\text{NHNH}_2$	
Potassium thiocyanate	KSCN	2*500 g
Sodium hydrogen carbonate	NaHCO_3	2*50 g
Urea	$(\text{NH}_2)_2\text{CO}$	1*250 g
Xylene	C_8H_{10}	4*450 mL
Nitrogen Compounds		
Acetonitrile	CH_3CN	2*2,500 mL
N-(2-Hydroxyethyl)morpholine	$\text{CH}_2(\text{CH}_2)_4\text{NCH}_2\text{CH}_2\text{OH}$	1*100 g
Ammonium molybdate	$(\text{NH}_4)_6\text{Mo}_7\text{O}_{24} \cdot 4\text{H}_2\text{O}$	1*500 g
Chloramine T	$\text{CH}_3\text{CH}_6\text{H}_4\text{SO}_2\text{NCINa} \cdot 3\text{H}_2\text{O}$	
Cone, ammonium solution (ammonium hydroxide)	NH_4OH	1*2.5 g
Coomassie Brilliant Blue R 250	$\text{C}_{45}\text{H}_{44}\text{N}_3\text{NaO}_7\text{S}_2$	35 g
4-Diamethylaminobenzaldehyde	$(\text{CH}_3)_2\text{NC}_6\text{H}_4\text{CHO}$	2*100 g
Nitrobenzene	$\text{C}_6\text{H}_5\text{NO}_2$	1*2,500 mL
p-Nitrophenylhydrazine	$\text{NO}_2\text{C}_6\text{H}_4\text{NHNH}_2$	
Potassium thiocyanate	KSCN	2*500 g
Urea	$(\text{NH}_2)_2\text{CO}$	1*250 g
Phosphorus Compounds		
Methanesulphonic acid	HPO_3	1*25 g
Methaphosphoric acid	HPO_3	1*500 g
Phosphorus pentoxide	P_2O_5	
Sulfur Compounds		
Coomassie Brilliant Blue R 250	$\text{C}_{45}\text{H}_{44}\text{N}_3\text{NaO}_7\text{S}_2$	35 g
Potassium thiocyanate	KSCN	2*500 g
Metals Compounds		
2,6-Dichlorophenolindophenol sodium salt	$\text{NaOC}_6\text{H}_4 \cdot \text{C}_6\text{H}_2(\text{Cl}_2) \cdot \text{O} \cdot 2\text{H}_2\text{O}$	1*10 g
Ammonium molybdate	$(\text{NH}_4)_6\text{Mo}_7\text{O}_{24} \cdot 4\text{H}_2\text{O}$	1*500 g
Chloramine T	$\text{CH}_3\text{CH}_6\text{H}_4\text{SO}_2\text{NCINa} \cdot 3\text{H}_2\text{O}$	
Coomassie Brilliant Blue R 250	$\text{C}_{45}\text{H}_{44}\text{N}_3\text{NaO}_7\text{S}_2$	35 g
Potassium permanganate	KMnO_4	1 *1,000 g
Potassium thiocyanate	KSCN	2*500 g
Sodium hydrogen carbonate	NaHCO_3	2*50 g

Table A-3. Chemical substances used in SUT laboratories in year 1996.

Chemical substances category	Formula	Quantity
Carbon Compounds		
Ethyl cyclohexane	$C_2H_5CO(CH_2)_4CH_2$	1*1,000 mL
Acetic acid glacial	CH_3COOH	1*2,500 mL
Acetone	CH_3COCH_3	2*2,500 mL
Acetonitrile	CH_3CN	2*2,500 mL
Aniline sulphate	$(C_6H_5NH_2).H_2SO_4$	500 g
Antimony potassium tartrate	$KOOC(CHOH)_2COOSbO.1/2H_2O$	2*250 g
Calcium carbonate	$CaCO_3$	2*1,000 g
Calcium chloride dihydrate	$CaCl_2.2H_2O$	2*1,000 g
Carbon tetrachloride	CCl_4	2,500 mL
Chloroform	$CHCl_3$	7*2,500 mL
Chloroform	$CHCl_3$	1*1,000 g
Crystal violet	$C_{25}H_{30}ClN_3$	25 g
D(+)-Glucose anhydrous	$CH_2OHCH(CHOH)_3CHOH$	500 g
Eosin Y	$C_{20}H_6Br_4NO_5$	100 g
Ethyl acetate	$CH_3COOC_2H_5$	5*2,500 mL
Ethyl alcohol absolute	C_2H_5OH	4*2,500 mL
Ethylenediaminetetraacetic acid disodium salt	$[CH_2N(CH_2COOH)CH_2COONa].2H_2O$	1*1,000 g
Formic acid 85%	$HCOOH$	2.5*1,000 mL
Glycol	$CH_2OHCHOHCH_2OH$	6*1,000 mL
L(+)-Ascorbic acid	$COCOH.COCHCHOHCH_2OH$	1*100 g
Lead(II)acetate	$Pb(CH_3COO)_2.3H_2O$	1*1,000 g
M-Butyl alcohol	$CH_3(CH_2)_2CH_2OH$	1*1,000 mL
Methyl alcohol	CH_3OH	2*2,500 mL
n-Hexane	$CH_3(CH_2)_4CH_3$	2*2,500 mL
Oxalic acid dihydrate	$(COOH)_2.2H_2O$	1.5*1,000 g
p-Cymene	$CH_3C_6H_4CH(CH_3)_2$	1*1,000 mL
Piperidine	$NH(CH_2)_4CH_2$	1*1,000 mL
Potassiumsodium tartrate	$COOK(CHOH)_2VOONS.4H_2O$	1*1,000 g
Sodium carbonate anhydrous	Na_2CO_3	2*1,000 g
Sodium hydroxide pellets	CO_2	1*1,000 g
Thymol blue	$C_6H_4SO_2OC[C_6H_2-2-CH_3-5-CH(CH_3)_2-4-OH]_2$	5 g
Toluene	$C_6H_5CH_3$	1*2,500 mL
Nitrogen Compounds		
Acetonitrile	CH_3CN	2*2,500 mL
Ammonia	NH_3	1*1,000 g
Ammonium molybdate	$(NH_4)_6Mo_7O_{24}.4H_2O$	1*1,000 g
Ammonium sulphate	$(NH_4)_2SO_4$	1*1,000 g
Aniline sulphate	$(C_6H_5NH_2).H_2SO_4$	500 g
Calcium nitrate	$Ca(NO_3)_2.4H_2O$	1*1,000 g
Crystal violet	$C_{25}H_{30}ClN_3$	25 g
Eosin Y	$C_{20}H_6Br_4NO_5$	100 g
Ethylenediaminetetraacetic acid disodium salt	$[CH_2N(CH_2COOH)CH_2COONa].2H_2O$	1*1,000 g
Hydroxylamine sulphate	$(NH_2OH)_2.H_2SO_4$	1*1,000 g

Table A-3. (continued) Chemical substances used in SUT laboratories in year 1996.

Chemical substances category	Formula	Quantity
Nitrogen Compounds		
Hydrozine sulphate	$\text{NH}_2\text{NH}_2 \cdot \text{S}_2\text{SO}_4$	1*2,500 mL
Piperidine	$\text{NH}(\text{CH}_2)_4\text{CH}_2$	1*1,000 mL
Potassiumsodium tartrate	$\text{COOK}(\text{CHOH})_2\text{VOONS} \cdot 4\text{H}_2\text{O}$	1*1,000 g
Silver nitrate	AgNO_3	100 g
Sodium nitrate	NaNO_3	1*1,500 g
Phosphorus Compounds		
di-Potassium hydrogen phosphate anhydrous	K_2HPO_4	250 g
di-Potassium hydrogen phosphate anhydrous	K_2HPO_4	1*1,000 g
di-Sodium hydrogen phosphate anhydrous	Na_2HPO_4	1*1,000 g
Phosphorous acid	H_3PO_3	1*2,500 mL
Phosphorus pentoxide	P_2O_5	1*1,000 mL
Potassium cdihydrogen phosphate	KH_2PO_4	1*1,000 g
Sodium dihydrogen phosphate	$\text{NaH}_2\text{PO}_4 \cdot \text{H}_2\text{O}$	1*1,000 g
Sulfur Compounds		
Ammonium sulphate	$(\text{NH}_4)_2\text{SO}_4$	1*1,000 g
Aniline sulphate	$(\text{C}_6\text{H}_5\text{NH}_2) \cdot \text{H}_2\text{SO}_4$	500 g
Cobalt(II)sulphate	$\text{CoSO}_4 \cdot 7\text{H}_2\text{O}$	250 g
Ferrus sulphate	FeSO_4	1*1,000 g
Hydroxylamine sulphate	$(\text{NH}_2\text{OH})_2 \cdot \text{H}_2\text{SO}_4$	1*1,000 g
Hydrozine sulphate	$\text{NH}_2\text{NH}_2 \cdot \text{S}_2\text{SO}_4$	1*2,500 mL
Lead(II)sulphate	PbSO_4	250 g
Mercury(II)sulphate	HgSO_4	2*250 g
Thymol blue	$\text{C}_6\text{H}_4\text{SO}_2\text{OC}[\text{C}_6\text{H}_2-2-\text{CH}_3-5-\text{CH}(\text{CH}_3)_2-4-\text{OH}]_2$	5 g
Zine sulphate monohydrate	$\text{ZnSO}_4 \cdot \text{H}_2\text{O}$	1*1,000 g
Metals Compounds		
Aluminium chloride	$\text{AlCl}_3 \cdot 6\text{H}_2\text{O}$	1*1,000 g
Aluminium hydroxide	$\text{Al}(\text{OH})_3$	500 g
Ammonium molybdate	$(\text{NH}_4)_6\text{Mo}_7\text{O}_{24} \cdot 4\text{H}_2\text{O}$	1*1,000 g
Antimony potassium tartrate	$\text{KOOOC}(\text{CHOH})_2\text{COOSbO} \cdot 1/2\text{H}_2\text{O}$	2*250 g
Barium chloride	$\text{BaCl}_2 \cdot 2\text{H}_2\text{O}$	1*1,000 g
Barium hydroxide	$\text{Ba}(\text{OH})_2 \cdot 3\text{H}_2\text{O}$	1*1,000 g
Calcium carbonate	CaCO_3	2*1,000 g
Calcium chloride dihydrate	$\text{CaCl}_2 \cdot 2\text{H}_2\text{O}$	2*1,000 g
Calcium fluoride	CaF_2	250 g
Calcium hydroxide	$\text{Ca}(\text{OH})_2$	1*1,000 g
Chromium(III)oxide	Cr_2O_3	1*1,000 g
Cobalt(II)Chloride	$\text{CoCl}_2 \cdot 6\text{H}_2\text{O}$	2*250 g
Cobalt(II)sulphate	$\text{CoSO}_4 \cdot 7\text{H}_2\text{O}$	250 g
di-Potassium hydrogen phosphate anhydrous	K_2HPO_4	250 g
di-Potassium hydrogen phosphate anhydrous	K_2HPO_4	1*1,000 g
di-Sodium hydrogen phosphate anhydrous	Na_2HPO_4	1*1,000 g
Ethylenediaminetetraacetic acid disodium salt	$[\text{CH}_2\text{N}(\text{CH}_2\text{COOH})\text{CH}_2\text{COONa}] \cdot 2\text{H}_2\text{O}$	1*1,000 g
Ferrus sulphate	FeSO_4	1*1,000 g

Table A-3. (continued) Chemical substances used in SUT laboratories in year 1996.

Chemical substances category	Formula	Quantity
Metals Compounds		
Lead(II)acetate	$Pb(CH_3COO)_2 \cdot 3H_2O$	1*1,000 g
Lead(II)sulphate	$PbSO_4$	250 g
Mercury(II)sulphate	$HgSO_4$	2*250 g
Nickel(II)chloride	$NiCl_2 \cdot 6H_2O$	250 g
Potassium cdihydrogen phosphate	KH_2PO_4	1*1,000 g
Potassium chloride	KCl	2*1,000 g
Potassium chloroplatimate	K_2PtCl_6	10*1 g
Potassium hydrogen iodate	$KIO_3 \cdot HIO_3$	1*50 g
Potassium hydroxide pellets	KOH	1*2,250 g
Potassium iodide	KI	1*100 g
Potassium persulphate	$K_2S_2O_8$	2,100 g
Potassium sulphate	K_2SO_4	1*1,000 g
Potassiumsodium tartrate	$COOK(CHOH)_2VOONS \cdot 4H_2O$	1*1,000 g
Silver chloride	$AgCl$	25 g
Silver nitrate	$AgNO_3$	100 g
Sodium carbonate anhydrous	Na_2CO_3	2*1,000 g
Sodium chloride	$NaCl$	1*1,000 g
Sodium dihydrogen phosphate	$NaH_2PO_4 \cdot H_2O$	1*1,000 g
Sodium hydroxide pellets	$NaOH$	32*1,000 g
Sodium iodide	NaI	1*500 g
Sodium iodide	NaI	1*500 g
Sodium nitrate	$NaNO_3$	3*500 g
Sodium sulphate anhydrous	Na_2SO_4	2*1,000 g
Zine sulphate monohydrate	$ZnSO_4 \cdot H_2O$	1*1,000 g

Table A-4. Chemical substances used in SUT laboratories in year 1997.

Chemical substances category	Formula	Quantity
Carbon Compounds		
o-Phenanthroline	$C_5H_3NCH:CHC_5H_3N \cdot H_2O$	
o-Phenanthroline-Iron(II)sulphate solution in sulphuric acid	$C_36H_{24}FeN_6O_4S$	8*100 mL
sym-Diphenylthiocarbazon	$C_6H_5NHNHCSN:NC_6H_5$	45 g
2-Mercaptoethanol	$HSCH_2CH_2OH$	100 mL
Methyl elaidinate	$CH_3(CH_2)_7CH:CH(CH_2)_7COOCH_3$	
5-Sulphosalicylic acid	$HO \cdot C_6H_3(COOH)SO_3H \cdot 2H_2O$	250 g
Acetic acid glacial	CH_3COOH	7*2,500 mL
Acetone analar	CH_3COCH_3	20*2,500 mL
Betaine	$(CH_3)_3NCH_2COO$	
Bromocresol Green Water Soluble	$C_{21}H_{14}Br_4O_5S$	2*5 g
Bromocresol Purple Solid	$C_{21}H_{16}Br_2O_5S$	50 g
Bromophenol Blue	$C_{19}H_{10}Br_4O_5S$	60 g
Calcium acetate	$Ca(CH_3COO)_2 \cdot nH_2O$	1*1,000 g

Table A-4. (continued) Chemical substances used in SUT laboratories in year 1997.

Chemical substances category	Formula	Quantity
Carbon Compounds		
Calcium carbonate	CaCO ₃	2,300 g
Carbon tetrachloride	CCl ₄	2.5*1,000 mL
Chloramine T	CH ₃ C ₆ H ₄ SO ₂ NCINa.3H ₂ O	
Chloroform	CHCl ₃	2*2,500 mL
Citric acid	COOHCH ₂ C(OH)COOHCH ₂ COOH.H ₂ O	1*1,000 g
Coomassie brilliant Blue	C ₄₅ H ₄₄ N ₃ NaO ₇ S ₂	10 g
Copper(II) Acetate GPR	Cu(CH ₃ COO) ₂ .nH ₂ O	6*500 g
D-Sorbitol	CH ₂ OH(CHOH) ₄ CH ₂ OH	250 g
Dichloromethane	CH ₂ Cl ₂	2.5*1,000 mL
Diethyl ether Analar	CH ₃ CH ₂ OCH ₂ CH ₃	2*2,500 mL
Diethylenetriaminepentacetic acid	[(HOOCCH ₂) ₂ NCH ₂ CH ₂] ₂ NCH ₂ COOH	1*1,000 mL
L(+)-Ascorbic acid	COCOH:COHCHCHOHCH ₂ OH	1*100 g
D-Mannitol	CH ₂ OH(CHOH) ₄ CH ₂ OH	2*1,000 g
EDTA	[CH ₂ N(CH ₂ COOH) ₂] ₂	100 g
EDTA disodium	[CH ₂ N(CH ₂ COOH)CH ₂ COONa] ₂ .2H ₂ O] ₂	2*500 g
Ethyl acetate	CH ₃ COOC ₂ H ₅	24,000 mL
Ethyl alcohol (absolute)	C ₂ H ₅ OH	32,000 mL
Ethylene Diamine Tetra -acetic Acid Analar	[CH ₂ N(CH ₂ COOH) ₂] ₂	12*250 g
Ethylene Diamine Tetra -acetic Acid Disodium salt	[CH ₂ N(CH ₂ COOH)CH ₂ COONa] ₂ .2H ₂ O] ₂	6*500 g
Ethyl alcohol(absolute)	C ₂ H ₅ OH	10*2,500 mL
Ferroun indicator	C ₃₆ H ₂₄ FeN ₆ O ₄ S	15*50 mL
Formaldehyde	HCHO	2,500 mL
Formamide	HCONH ₂	1*1,000 mL
Glucose Analar	CH ₂ OHCH(CHOH) ₃ CHOH	10*500 g
Glycerol analar	CH ₂ OHCHOHCH ₂ OH	1*2,500 mL
Lauryl alcohol	CH ₃ (CH ₂) ₁₀ CH ₂ OH	
Lead acetate	Pb(CH ₃ COO) ₄	2*250 g
L(+)-Glutamic acid	HOOCCH(NH ₂)CH ₂ CH ₂ COOH	
L-Glutamic Acid Sodium Salt	HOOCCH(NH ₂)CH ₂ CH ₂ COOH	2*500 g
L-Iso Leucine, Sigma#I-2752	(CH ₃)CHCH ₂ CHNH ₂ COOH	1*100 g
L-Tryptophane, Fluka	C ₆ H ₄ NHCH:CCH ₂ CHNH ₂ COOH	1*25 g
Methanol Analar	CH ₃ OH	16*2,500 mL
N-Acetyglycine	CH ₃ CONHCH ₂ COOH	
Napthalene GPR	C ₁₀ H ₈	20*500 g
Anisaldehyde	4-CH ₃ O-C ₆ H ₄ CHO	1*100 mL
Phenol	C ₆ H ₅ OH	1*1,000 g
Phenol Red(pH indicator) solid	C ₆ H ₅ OH	5*10 g
Phenolphthalein (pH indicator) solid	C ₆ H ₄ COOC(C ₆ H ₄ -4-OH) ₂	5*100 g
p-Nitrophenol	NO ₂ C ₆ H ₄ OH	1*5 g
Potassium hexacyanoferrate(III)	K ₃ Fe(CN) ₆	
Potassium sodium tartrate ,Ajax	COOK(CHOH) ₂ COONa.4H ₂ O	4*500 g
Potassium thiocyanate Analar	KSCN	1*500 g
Riboflavin (vitamin B 2) Fluka	C ₁₇ H ₂₀ O ₆ N ₄	3*10 g

Table A-4. (continued) Chemical substances used in SUT laboratories in year 1997.

Chemical substances category	Formula	Quantity
Carbon Compounds		
Safranine RPE	$C_{20}H_{19}ClN_4$	25 g
Salicylic acid	2-HOC ₆ H ₄ COOH	100 g
Sodium acetate	$CH_3COONa \cdot 3H_2O$	1*1,000 g
Sodium carbonate	Na_2CO_3	6.5 *1,000 g
Sodium glutamate	$NaOOC(CH_2)_2CH(NH_2)COOH \cdot H_2O$	1*1,000 g
Sucrose GPR	$C_{12}H_{22}O_{11}$	10*500 g
Sulphanilamide	$C_6H_8O_2N_2S$	250 g
Toluene	$C_6H_5CH_3$	4*1,000 mL
Xylenecyanol	$C_{25}H_{27}N_2NaO_7S_2$	10 g
Zinc acetate	$Zn(CH_3COO)_2 \cdot 2H_2O$	1*500 g
Nitrogen Compounds		
o-Phenanthroline	$C_5H_3NCH:CHC_5H_3N \cdot H_2O$	
o-Phenanthroline-Iron(II)sulphate solution in sulphuric acid	$C_{36}H_{24}FeN_6O_4S$	8*100 mL
sym-Diphenylthiocarbazone	$C_6H_5NHNHCSN:NC_6H_5$	45 g
N-Acetylimidazole	$CH:NCH:CHNCOCH_3$	
Ammonium acetate	CH_3COONH_4	6*1,000 g
Ammonia Soln.30 %	NH_4OH	9,500 mL
Ammonium Chloride Analar	NH_4Cl	4*500 g
Ammonium fluoride	NH_4F	12*250 g
Ammonium Meta-Vanadate Analar	NH_4VO_3	20*100 g
Ammonium Molybdate	$(NH_4)_6Mo_7O_{24} \cdot 4H_2O$	3*1,000 g
Ammonium hydrogen sulphate	NH_4HSO_4	
Ammonium persulphate	$(NH_4)_2S_2O_8$	
Azomethine H	$C_{17}H_{10}N_2NaO_8S_2$	
Azolbenzene	$C_6H_5N:NC_6H_5$	
Barium nitrate	$Ba(NO_3)_2$	2*1,000 g
Betaine	$(CH_3)_3NCH_2COO$	
Chloramine T	$CH_3C_6H_4SO_2NCNa \cdot 3H_2O$	
Coomassie brilliant Blue	$C_{45}H_{44}N_3NaO_7S_2$	10 g
Diethylenetriaminepentacetic acid	$[(HOOCCH_2)_2NCH_2CH_2]_2NCH_2COOH$	1*1,000 mL
EDTA	$[CH_2N(CH_2COOH)_2]_2$	100 g
EDTA disodium	$[CH_2N(CH_2COOH)CH_2COONa]_2 \cdot 2H_2O$	2*500 g
Ethylene Diamine Tetra -acetic Acid Analar	$[CH_2N(CH_2COOH)_2]_2$	12*250 g
Ethylene Diamine Tetra -acetic Acid Disodium salt	$[CH_2N(CH_2COOH)CH_2COONa]_2 \cdot 2H_2O$	6*500 g
Ferriin indicator	$C_{36}H_{24}FeN_6O_4S$	15*50 mL
Ferrous ammonium sulfate	$FeNH_4(SO_4)_2 \cdot 12H_2O$	6*1,000 g
Formamide	$HCONH_2$	1*1,000 mL
Hydroxylamine hydrochloride	$NH_2OH \cdot HCl$	1*500 g
L(+)-Glutamic acid	$HOOCCH(NH_2)CH_2CH_2COOH$	
L-Glutamic Acid Sodium Salt	$HOOCCH(NH_2)CH_2CH_2COOH$	2*500 g
L-Iso Leucine, Sigma#I-2752	$(CH_3)CHCH_2CHNH_2COOH$	1*100 g
L-Tryptophane, Fluka	$C_6H_4NHCH:CCH_2CHNH_2COOH$	1*25 g
N-Acetylglycine	$CH_3CONHCH_2COOH$	

Table A-4. (continued) Chemical substances used in SUT laboratories in year 1997.

Chemical substances category	Formula	Quantity
Nitrogen Compounds		
Nitric acid	HNO ₃	3*2,500 mL
p-Nitrophenol	NO ₂ C ₆ H ₄ OH	1*5 g
Potassium hexacyanoferrate(III)	K ₃ Fe(CN) ₆	
Potassium thiocyanate Analar	KSCN	1*500 g
Riboflavin (vitamin B 2) Fluka	C ₁₇ H ₂₀ O ₆ N ₄	3*10 g
Safranine RPE	C ₂₀ H ₁₉ ClN ₄	25 g
Silver nitrate analar	AgNO ₃	2*100 g
Sodium azide	NaN ₃	250 g
Sodium glutamate	NaOOC(CH ₂) ₂ CH(NH ₂)COOH.H ₂ O	1*1,000 g
Sodium nitrate	NaNO ₂	3*1,000 g
Sulphanilamide	C ₆ H ₈ O ₂ N ₂ S	250 g
Xylenecyanol	C ₂₅ H ₂₇ N ₂ NaO ₇ S ₂	10 g
Phosphorus Compounds		
Potassium dihydrogen phosphate	KH ₂ PO ₄	4*500 g
di-Sodium hydrogen phosphate anhydrous	Na ₂ HPO ₄	2*100 g
Orthophosphoric acid	H ₃ PO ₄	
Potassium dihydrogen phosphate Anhydrous Analar	KH ₂ PO ₄	2*500 g
Sodium pyrophosphate analar	Na ₄ P ₂ O ₇ .10H ₂ O	2*500 g
Sulfur Compounds		
o-Phenanthroline-Iron(II)sulphate solution in sulphuric acid	C ₃₆ H ₂₄ FeN ₆ O ₄ S	8*100 mL
2-Mercaptoethanol	HSCH ₂ CH ₂ OH	100 mL
Ammonium hydrogen sulphate	NH ₄ HSO ₄	
Ammonium persulphate	(NH ₄) ₂ S ₂ O ₈	
Azomethine H	C ₁₇ H ₁₂ NNaO ₈ S ₂	
Bromocresol Green Water Soluble	C ₂₁ H ₁₄ Br ₄ O ₅ S	2*5 g
Bromocresol Purple Solid	C ₂₁ H ₁₆ Br ₂ O ₅ S	50 g
Bromophenol Blue	C ₁₉ H ₁₀ Br ₄ O ₅ S	60 g
Calcium Sulfate 2 Hydrate Analar	CaSO ₄ .2H ₂ O	1*2,000 g
Chloramine T	CH ₃ C ₆ H ₄ SO ₂ NCINa.3H ₂ O	
Coomassie brilliant Blue	C ₄₅ H ₄₄ N ₃ NaO ₇ S ₂	10 g
Copper(II) Sulfate Analar	CuSO ₄ .5S ₂ O	1*1,000 g
Ferriin indicator	C ₃₆ H ₂₄ FeN ₆ O ₄ S	15*50 mL
Ferrous ammonium sulfate	FeNH ₄ (SO ₄) ₂ .12H ₂ O	6*1,000 g
Ferrous Sulfate	FeSO ₄ .7H ₂ O	10*1,000 g
Potassium Sulfate	K ₂ SO ₄	1*1,000 g
Potassium sulfate	K ₂ SO ₄	5*1,000 g
Potassium thiocyanate Analar	KSCN	1*500 g
Silver sulfate	Ag ₂ SO ₄	2*100 g
Sodium dithionite,Fluka	Na ₂ S ₂ O ₄	1*500 g
Sodium fluorosilicate	Na ₂ SIF ₆	
Sodium sulfate anhydrous	Na ₂ SO ₄	6*1,000 g
Sodium thiosulphate	Na ₂ S ₂ O ₃ .5H ₂ O	500 g
Sulphuric acid	H ₂ SO ₄	5*2,500 mL

Table A-4. (continued) Chemical substances used in SUT laboratories in year 1997.

Chemical substances category	Formula	Quantity
Sulfur Compounds		
Sulphanilamide	$C_6H_8O_2N_2S$	250 g
Xylenecyanol	$C_{25}H_{27}N_2NaO_7S_2$	10 g
Metals Compounds		
Ammonium Meta-Vanadate Analar	NH_4VO_3	20*100 g
Ammonium Molybdate	$(NH_4)_6Mo_7O_{24}.4H_2O$	1*1,000 g
Azomethine H	$C_{17}H_{12}NNaO_8S_2$	
Barium Chloride	$BaCl_2.2H_2O$	5.5*1,000 g
Barium nitrate	$Ba(NO_3)_2$	2*1,000 g
Cadmium metal (powder)	Cd	2*250 g
Calcium acetate	$Ca(CH_3COO)_2.nH_2O$	1*1,000 g
Calcium carbonate	$CaCO_3$	2,300 g
Calcium Chloride Analar	$CaCl_2.6H_2O$	10*500 g
Calcium Hydroxide Analar	$Ca(OH)_2$	4*500 g
Calcium Sulfate 2 Hydrate Analar	$CaSO_4.2H_2O$	1*2,000 g
Chloramine T	$CH_3C_6H_4SO_2NCINa.3H_2O$	
Coomassie brilliant Blue	$C_{45}H_{44}N_3NaO_7S_2$	10 g
Copper(II) Acetate GPR	$Cu(CH_3COO)_2.nH_2O$	6*500 g
Copper(II) Sulfate Analar	$CuSO_4.5S_2O$	1*1,000 g
Potassium dihydrogen phosphate	KH_2PO_4	4*500 g
di-Sodium hydrogen phosphate anhydrous	Na_2HPO_4	2*100 g
EDTA disodium	$[CH_2N(CH_2COOH)CH_2COONa]_2.2H_2O]_2$	2*500 g
Ethylene Diamine Tetra -acetic Acid Disodium salt	$[CH_2N(CH_2COOH)CH_2COONa]_2.2H_2O]_2$	6*500 g
Ferric chloride anhydrous	$FeCl_3.6H_2O$	1*1,000 g
Feroin indicator	$C_36H_{24}FeN_6O_4S$	15*50 mL
Ferrous ammonium sulfate	$FeNH_4(SO_4)_2.12H_2O$	6*1,000 g
Ferrous Sulfate	$FeSO_4.7H_2O$	10*1,000 g
Lead acetate	$Pb(CH_3COO)_4$	2*250 g
Lithium chliloride	LiCl	5*1,000 g
Magnesium chloride	$MgCl_2.6H_2O$	6*1,000 g
Manageness Sulfate GPR 4 HYDRATE	$MgSO_4.7H_2O$	4*500 g
Mercury(II) Chloride	$HgCl_2$	6*250 g
Mercuriy(II)Sulfate Analar	$HgSO_4$	4*100 g
Mercury(II) iodide	HgI_2	250 g
Potassium Sulfate	K_2SO_4	1*1,000 g
Potassium Bromate Analar	$KBrO_3$	8*100 g
Potassium Chlomite Analar	K_2CrO_4	8*250 g
Potassium Chloride GPR	KCl	1*1,000 g
Potassium dichromate	$K_2Cr_2O_7$	2*1,000 g
Potassium dihydrogen phosphate Anhydrous Analar	KH_2PO_4	2*500 g
Potassium hexacyanoferrate(III)	$K_3Fe(CN)_6$	
Potassium hydrogen iodate	$KIO_3.HIO_3$	1*100 g
Potassium hydroxide	KOH	7*1,000 g
Potassium iodate	KIO_3	500 g

Table A-4. (continued) Chemical substances used in SUT laboratories in year 1997.

Chemical substances category	Formula	Quantity
Metals Compounds		
Potassium iodide	KI	3*1,000 g
Potassium nitrate Analar	KNO ₃	2*500 g
Potassium permanganate Analar	KMnO ₄	2*1,000 g
Potassium sodium tartrate ,Ajax	COOK(CHOH) ₂ COONa.4H ₂ O	4*500 g
Potassium sulfate	K ₂ SO ₄	5*1,000 g
Potassium thiocyanate Analar	KSCN	1*500 g
Silver nitrate analar	AgNO ₃	2*100 g
Silver sulfate	Ag ₂ SO ₄	2*100 g
Sodium acetate	CH ₃ COONa.3H ₂ O	1*1,000 g
Sodium arsenite	NaAsO ₂	1*500 g
Sodium azide	NaN ₃	250 g
Sodium cabonate	Na ₂ CO ₃	6.5 *1,000 g
Sodium chloride	NaCl	17*1,000 g
Sodium dicromate GPR	Na ₂ Cr ₂ O ₇ .2H ₂ O	12*500 g
Sodium dithionite,Fluka	Na ₂ S ₂ O ₄	1*500 g
Sodium fluorosilicate	Na ₂ SIF ₆	
Sodium glutamate	NaOOC(CH ₂) ₂ CH(NH ₂)COOH.H ₂ O	1*1,000 g
Sodium hydroxide	NaOH	28*1,000 g
Sodium iodide	NaI	500 g
Sodium Molybdate GPR	Na ₂ MoO ₄ .2H ₂ O	1*500 g
Sodium nitrate	NaNO ₂	1*1,000 g
Sodium pyrophosphate analar	Na ₄ P ₂ O ₇ .10H ₂ O	2*500 g
Sodium sulfate anhydrous	Na ₂ SO ₄	6*1,000 g
Sodium thiosulphate	Na ₂ S ₂ O ₃ .5H ₂ O	500 g
Xylenecyanol	C ₂₅ H ₂₇ N ₂ NaO ₇ S ₂	10 g
Zine acetate	Zn(CH ₃ COO) ₂ .2H ₂ O	1*500 g
Zine sulfate eptahydrate Analar	ZnSO ₄ .7H ₂ O	1*1,000 g

Table A-5. Chemical substances used in SUT laboratories in year 1998.

Chemical substances category	Formula	Quantity
Carbon Compounds		
Phenantholein	$C_5H_4CH:CHC_6H_4$	10*1,000 g
Nitrobenzene	$C_6H_5NO_2$	50 mL
2,6-Dichlorophenolindophenol sodium salt	$NaOC_6H_4N:C_6H_2(Cl)_2:O.2H_2O$	5 g
1-Amnio-2-methyl-1,3-propanediol	$(HOCH_2)_2C(NH_2)CH_3$	1*1,000 mL
2-Ethoxyethanol	$CH_3CH_2OCH_2CH_2OH$	4*1,000 mL
2-Mercaptoethanol M.6250	$CH_3CH_2OCH_2CH_2OH$	1,100 mL
2-Mercaptoethanol sigma	$HSCH_2OH$	100 mL
3,5-Dinitrosalicylic acid purum	$(NO_2)_2C_6H_2(OH)COOH.nH_2O$	25 g
Allyl alcohol	$CH_2:CHCH_2OH$	12*2,500 mL
Methyl alcohol	CH_3OH	4*2,500 mL
Acetanilide	$CH_3CONHC_6H_5$	1*1,000 g
Acetic acid	CH_3COOH	37,000 mL
Acetone	CH_3COCH_3	60.51*1,000 mL
Acetone anhydrous sigma	CH_3COCH_3	2,505 g
Acetonitrile for chromatography	CH_3CN	2,500 mL
Acetylcholine chloride purum	$(CH_3)_3N(Cl)CH_2CH_2OCOCH_3$	25 g
Acrylonitrile	$CH_2:CHCN$	100 g
Alizarin pH 6-12	$C_{14}H_8O_4$	1*25 g
Ammonium acetate	CH_3COONH_4	1*1,000 g
Ammonium oxalate	$(NH_4)_2C_2O_4.H_2O$	1*500 g
Azomethine H	$C_{17}H_{12}NNaO_8S_2$	2 g
Barium acetate	$Ba(CH_3COO)_2$	500 g
Barium carbonate	$BaCO_3$	1*1,000 g
Benzene GC grade	C_6H_6	4*1,000 mL
Benzoic acid	C_6H_5COOH	1 g
Bromocresol green	$C_{21}H_{14}Br_4O_5S$	5 g
Bromophenol Blue	$C_{19}H_{10}Br_4O_5S$	10 g
Calcium Chloride	$CaCl_2.6H_2O$	52*1,000 g
Carbon Tetrachloride	CCl_4	10*1,000 mL
Carotene	$C_{40}H_{56}$	5 mg
Chloroform AR	$CHCl_3$	7,600 mL
Chlorophenol red	$C_{19}H_{12}Cl_2O_5S$	5 g
Coomassie Brilliant Blue	$C_{45}H_{44}N_3NaO_7S_2$	25 g
o-Cresol red	$C_{21}H_{18}O_5S$	1*500 g
Crystal Violet	$C_{25}H_{30}ClN_3$	25 g
Cyclohexane RPE	$CH_2(CH_2)_4CH_2$	3*2,500 mL
Dextrose	$CH_2OHCH(CHOH)_3CHOH$	1*1,000 g
di-chloromethane for chromatography	CH_2Cl_2	2,500 mL
1,3-Dicyclohexylcarbodiimide	$C_6H_{11}N:C:NC_6H_{11}$	1*500 mL
4-Dimethylaminobenzaldehyde	$(CH_3)_2NC_6H_4CHO$	100 g
Dithiol	$CH_3C_6H_3(SH)_2$	1 g
DL-Malic acid	$HOOCCH(OH)CH_2COOH$	1*1,000 g
D-Mannitol	$CH_2OH(CHOH)_4CH_2OH$	750 g

Table A-5. (continued) Chemical substances used in SUT laboratories in year 1998.

Chemical substances category	Formula	Quantity
Carbon Compounds		
EDTA disodium salt	$[\text{CH}_2\text{N}(\text{CH}_2\text{COOH})\text{CH}_2\text{COONa}]_2 \cdot 2\text{H}_2\text{O}$	3,100 g
Eosin-methylene blue	$\text{C}_{20}\text{H}_6\text{Br}_2\text{N}_2\text{Na}_2\text{O}_9$	500 g
Ethanol 95%	$\text{C}_2\text{H}_5\text{OH}$	56.5*1,000 mL
Ethyl bromide Fluka	$\text{C}_2\text{H}_5\text{Br}$	1 g
Ethyl acetate	$\text{CH}_3\text{COOC}_2\text{H}_5$	20.25 *1,000 mL
Ethyl methyl ether	$\text{C}_3\text{H}_8\text{O}$	5,000 mL
Formaldehyde	HCHO	2,500 mL
Formalin 40%	CH_2O	20*2,500 mL
Formamide	HCONH_2	1,000 mL
Glycerol RPE-ACS	$\text{CH}_2\text{OHCHOHCH}_2\text{OH}$	5*1,000 mL
Glycine	$\text{CH}_2\text{NH}_2\text{COOH}$	600 g
Guaiacol	$\text{HC}_6\text{H}_4\text{OCH}_3$	200 g
n-Heptane	$\text{CH}_3(\text{CH}_2)_5\text{CH}_3$	50 g
n-Hexane	$\text{CH}_3(\text{CH}_2)_4\text{CH}_3$	9*1,000 mL
Hydroquinone	$1,4\text{-(CO)}_2\text{C}_6\text{H}_4$	1*1,000 g
Imidazole	$\text{C}_3\text{H}_4\text{N}_2$	100 g
Isobutyl alcohol	$(\text{CH}_3)_2\text{CHCH}_2\text{OH}$	1*1,000 mL
Isopropanol	$\text{CH}_3\text{CHOHCH}_3$	16*1,000 mL
Propyl gallate	$\text{C}_{10}\text{H}_{12}\text{O}_5$	250 g
Isoamyl alcohol	$\text{C}_5\text{H}_{11}\text{OH}$	1*1,000 mL
L - Lysine monohydrochloride	$\text{NH}_2(\text{CH}_2)_4\text{CHNH}_2\text{COOH} \cdot \text{HCl}$	5 g
Lactose broth	$\text{C}_{12}\text{H}_{22}\text{O}_{11} \cdot \text{H}_2\text{O}$	10*500 g
L-Glutamic acid	$\text{HCCOOCCH}(\text{NH}_2)\text{CH}_2\text{CH}_2\text{COOH}$	100 g
L-Leucine	$(\text{CH}_3)_2\text{CHCH}_2\text{CHNH}_2\text{COOH}$	25 g
L-tyrosine	$4\text{-HOC}_6\text{H}_4\text{CH}_2\text{CHNH}_2\text{COOH}$	25 g
Magnesium carbonate	$(\text{MgCO}_3)_4 \cdot \text{Mg}(\text{OH})_2 \cdot 5\text{H}_2\text{O}$	1*1000 g
Methanol	CH_3OH	107.5 *1,000 mL
Methyl red	$\text{C}_{15}\text{H}_{15}\text{N}_3\text{O}_2$	1*50 g
Methyl sulphate	$\text{CH}_4\text{O}_4\text{S}$	25 mL
Methylene blue	$\text{C}_{16}\text{H}_{18}\text{ClN}_3\text{S}$	600 g
Methylene Chloride	CH_2Cl_2	1*1,000 mL
Methyl alcohol	CH_3OH	1*2,500 mL
D-Glucosamine	$\text{C}_6\text{H}_{13}\text{NO}_5$	5 g
Napthalene	C_{10}H_8	1*1,000 g
Benzyl ethyl ether	$\text{C}_9\text{H}_{12}\text{O}$	25 g
n-Hexane	$\text{CH}_3(\text{CH}_2)_4\text{CH}_3$	17.5 *1,000 mL
Nile blue A Color	$\text{C}_{20}\text{H}_{21}\text{N}_3\text{O}_5\text{S}$	2*50 g
Nitrobenzene	$\text{C}_6\text{H}_5\text{NO}_2$	2*1,000 mL
2-propanol	$\text{CH}_3\text{CHOHCH}_3$	1*2,500 mL
D(-)p-Nitrophenyl-1-amino-2-propane-1,3-diol	$\text{NO}_2\text{C}_6\text{H}_4\text{CHOHCH}(\text{NH}_2)\text{CH}_2\text{OH}$	1 g
o-Phthalaldehyde	$\text{C}_6\text{H}_4(\text{CHO})_2$	5 g
Anisaldehyde	$4\text{-CH}_3\text{OC}_6\text{H}_4\text{CHO}$	100 mL
p-Dichlorobenzene	$\text{C}_6\text{H}_4\text{Cl}_2$	1*1,000 g

Table A-5. (continued) Chemical substances used in SUT laboratories in year 1998.

Chemical substances category	Formula	Quantity
Carbon Compounds		
Streptomycin,sulfate	$C_{42}H_{84}N_{14}O_{36}S_3$	100 mL
Phenol	C_6H_5OH	4*25 g
Phenol red	$C_{19}H_{14}O_5S$	1,005 g
p-Nitrophenol Sigma	$NO_2C_6H_4OH$	105 g
Ethylene glycol diethyl ether	$C_6H_{14}O_2$	100 g
Tartar emetic	$C_8H_{10}K_2O_{15}Sb_2$	500 g
Potassium Carbonate	K_2CO_3	1*1,000 g
Potassium sodium tartrate	$COOK(CHOH)_2COONa.4H_2O$	4.5*1,000 g
Pyridine-d5	C_5D_5N	5 mL
Quinine-Sulphate	$C_{40}H_{50}N_4O_8S$	25 g
Benzene-d6	C_6D_6	10 mL
Sodium acetate	$CH_3COONa.3H_2O$	4*250 g
Sodium Alginate	$(C_6H_7O_6Na)_n$	2*1,000 g
Sodium carbonate	Na_2CO_3	10 *1,000 g
Sodium ethylmercuriothiosalicylate	$C_9H_9HgNaO_2S$	5*1,000 g
Sodium tartrate	$(CHOHCOONa)_2.2H_2O$	1*1,000 g
Sodium thiocyanate	$NaSCN$	100 g
Sodium carbonate	Na_2CO_3	1*500 g
Sorbitol solution 70% in water	$C_6H_{14}O_6$	1 g
Streptomysin sulfate Biochem	$C_{42}H_{84}O_{36}S_{32}$	25 g
Sucrose	$C_{12}H_{22}O_{11}$	2,100 g
Sulphanilamide	$C_6H_8O_2N_2S$	500 g
Tannic Acid	$C_{76}H_{52}O_{46}$	100 g
Tartazine	$C_{16}H_9N_4Na_3O_9S_2$	5*100 g
Taurine	$NH_2CH_2CH_2SO_3H$	5 g
Tetrahydrofuran	$OCH_2CH_2CH_2CH_2$	2*2,500 mL
Tetramethylsilane	$(CH_3)_4Si$	25 mL
Tetrazolium Chloride	$C_{40}H_{32}N_8O_2Cl_2$	500 g
Tetrapropyl ammonium	$C_{12}H_{28}IN$	400 g
o-Tolidine	$C_{14}H_{16}N_2$	255 g
Toluene	$C_6H_5CH_3$	11.5 *1,000 mL
Tributylamine	$(CH_3CH_2CH_2CH_2)_3N$	250 mL
Trichloroacetic Acid	CCl_3COOH	1,100 g
Triethanolamine	$(CH_2OHCH_2)_3N$	2*500 g
Tris(hydroxymethyl)aminomethane	$NH_2C(CH_2OH)_3$	500 g
tri-Sodium citrate	$NaC_6H_5O_7.2H_2O$	2,000 g
Xanthine gum	$CONHCONHC:CNHCHN$	1*100 g
Xylene	C_8H_{10}	2*1,000 mL
D(+)-Xylose Fluka	$CH_2(CHOH)_3CHOH$	510 g
zinc Acetate Dihydrate	$Zn(CH_3COO)_2.2H_2O$	500 g
Nitrogen Compounds		
Nitrobenzene	$C_6H_5NO_2$	50 mL
2,6-Dichlorophenolindophenol sodium salt	$NaOC_6H_4N:C_6H_2(Cl)_2:O.2H_2O$	5 g

Table A-5. (continued) Chemical substances used in SUT laboratories in year 1998.

Chemical substances category	Formula	Quantity
Nitrogen Compounds		
1-Amnio-2-methyl-1,3-propanediol	$(\text{HOCH}_2)_2\text{C}(\text{NH}_2)\text{CH}_3$	1*1,000 mL
3,5-Dinitrosalicylic acid purum	$(\text{NO}_2)_2\text{C}_6\text{H}_2(\text{OH})\text{COOH} \cdot n\text{H}_2\text{O}$	25 g
Acetanilide	$\text{CH}_3\text{CONHC}_6\text{H}_5$	1*1,000 g
Acetonitrile for chromatography	CH_3CN	2.5*1,000 mL
Acetylcholine chloride purum	$(\text{CH}_3)_3\text{N}(\text{Cl})\text{CH}_2\text{CH}_2\text{OCOCH}_3$	25 g
Acrylonitrile	$\text{CH}_2=\text{CHCN}$	100 g
Ammonia sulphide solution 20% in water	$(\text{NH}_4)_2\text{S}$	18*1,000 g
Ammonia solution	$(\text{NH}_4)_2\text{S}$	2*1,000 mL
Ammonium acetate	$\text{CH}_3\text{COONH}_4$	1*1,000 g
Ammonium chloride AR	NH_4Cl	2*1,000 g
Ammonium Hydroxide	NH_4OH	5,000 mL
Ammonium Metavanadate	NH_4VO_3	500 g
Ammonium nitrate	NH_4NO_3	1*500 g
Ammonium oxalate	$(\text{NH}_4)_2\text{C}_2\text{O}_4 \cdot \text{H}_2\text{O}$	1*500 g
Ammonium Persulfate	$(\text{NH}_4)_2\text{S}_2\text{O}_8$	4*1,000 g
Ammonia solution	NH_4OH	4*1,000 mL
A-nitrate AR	$\text{Al}(\text{NO}_3)_3 \cdot 9\text{H}_2\text{O}$	500 g
Azomethine H	$\text{C}_{17}\text{H}_{12}\text{NNaO}_8\text{S}_2$	2 g
Cobalt nitrate	$\text{Co}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$	250 g
Coomassie Brilliant Blue	$\text{C}_{45}\text{H}_{44}\text{N}_3\text{NaO}_7\text{S}_2$	25 g
Crystal Violet	$\text{C}_{25}\text{H}_{30}\text{ClN}_3$	25 g
1,3-Dicyclohexylcarbodiimide	$\text{C}_6\text{H}_{11}\text{N}:\text{C}:\text{NC}_6\text{H}_{11}$	1*500 mL
4-Dimethylaminobenzaldehyde	$(\text{CH}_3)_2\text{NC}_6\text{H}_4\text{CHO}$	100 g
EDTA disodium salt	$[\text{CH}_2\text{N}(\text{CH}_2\text{COOH})\text{CH}_2\text{COONa}]_2 \cdot 2\text{H}_2\text{O}$	3,100 g
Eosin-methylene blue	$\text{C}_{20}\text{H}_6\text{Br}_2\text{N}_2\text{Na}_2\text{O}_9$	500 g
Formamide	HCONH_2	1*1,000 mL
Glycine	$\text{CH}_2\text{NH}_2\text{COOH}$	600 g
Hydroxylamine	H_2NOH	1*1,000 g
Imidazole	$\text{C}_3\text{H}_4\text{N}_2$	100 g
L - Lysine monohydrochloride	$\text{NH}_2(\text{CH}_2)_4\text{CHNH}_2\text{COOH} \cdot \text{HCl}$	5 g
L-Glutamic acid	$\text{HCCOOCCH}(\text{NH}_2)\text{CH}_2\text{CH}_2\text{COOH}$	100 g
L-Leucine	$(\text{CH}_3)_2\text{CHCH}_2\text{CHNH}_2\text{COOH}$	25 g
L-tyrosine	$4\text{-HOC}_6\text{H}_4\text{CH}_2\text{CHNH}_2\text{COOH}$	25 g
Methyl red	$\text{C}_{15}\text{H}_{15}\text{N}_3\text{O}_2$	1*50 g
Methylene blue	$\text{C}_{16}\text{H}_{18}\text{ClN}_3\text{S}$	600 g
D-Glucosamine	$\text{C}_6\text{H}_{13}\text{NO}_5$	5 g
Nickel nitrate	$\text{Ni}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$	250 g
Nile blue A Color	$\text{C}_{20}\text{H}_{21}\text{N}_3\text{O}_5\text{S}$	2*50 g
Nitric Acid	HNO_3	25*1,000 mL
Nitrobenzene	$\text{C}_6\text{H}_5\text{NO}_2$	2*1,000 mL
D(-)p-Nitrophenyl-1-amino-2-propane-1,3-diol	$\text{NO}_2\text{C}_6\text{H}_4\text{CHOHCH}(\text{NH}_2)\text{CH}_2\text{OH}$	1 g
Streptomycin,sulfate	$\text{C}_{42}\text{H}_{84}\text{N}_{14}\text{O}_{36}\text{S}_3$	100 mL
p-Nitrophenol Sigma	$\text{NO}_2\text{C}_6\text{H}_4\text{OH}$	105 g

Table A-5. (continued) Chemical substances used in SUT laboratories in year 1998.

Chemical substances category	Formula	Quantity
Nitrogen Compounds		
Pyridine-d5	C ₅ D ₅ N	5 mL
Silver Nitrate	AgNO ₃	450 g
Sodium nitrate	NaNO ₃	8.5*1,000 g
Sodium thiocyanate	NaSCN	100 g
Sulphamic acid	NH ₂ SO ₃ H	25*1,000 g
Sulphanilamide	C ₆ H ₈ O ₂ N ₂ S	500 g
Tartarazine	C ₁₆ H ₉ N ₄ Na ₃ O ₉ S ₂	5*100 g
Taurine	NH ₂ CH ₂ CH ₂ SO ₃ H	5 g
Tetrazolium Chloride	C ₄₀ H ₃₂ N ₈ O ₂ Cl ₂	500 g
Tetrapropyl ammonium	C ₁₂ H ₂₈ IN	400 g
o-Tolidine	C ₁₄ H ₁₆ N ₂	255 g
Tributylamine	(CH ₃ CH ₂ CH ₂ CH ₂) ₃ N	250 mL
Triethanolamine	(CH ₂ OHCH ₂) ₃ N	2*500 g
Tris(hydroxymethyl)aminomethane	NH ₂ C(CH ₂ OH) ₃	500 g
Xanthine gum	CONHCONHC:CNHCHN	1*100 g
Phosphorus Compounds		
Phosphorus pentoxide	P ₂ O ₅	100 g
di-Potassium hydrogen phosphate RPE	K ₂ HPO ₄	1,750 g
di-sodium hydrogen phosphate anhydrous	Na ₂ HPO ₄ .nH ₂ O	1,005 g
tri-Sodium phosphate	Na ₃ PO ₄ .12H ₂ O	1*500 g
Lead standard solution 1000 mg/l	Pb	500 mL
Metaphosphoric	HPO ₃	500 g
Orthophosphoric acid	H ₃ PO ₄	2.5*1,000 mL
Potassium dihydrogen phosphate	KH ₂ PO ₄	4*500 g
Sodium dihydrogen phosphate	NaH ₂ PO ₄ .H ₂ O	50 g
Sodium hexametaphosphate	(NaPO ₃) ₆	1*2,500 g
Sodium phosphate RPE-ACS	Na ₃ PO ₄	4*1,000 g
Tetrasodium pyrophosphate anhydrous	Na ₄ P ₂ O ₇ .10H ₂ O	1*1,000 g
tri-Sodium phosphate	Na ₃ PO ₄ .12H ₂ O	3*1,000 g
Sulfur Compounds		
2-Mercaptoethanol sigma	HSCH ₂ OH	100 mL
Ammonia sulphide solution 20% in water	(NH ₄) ₂ S	18*1,000 g
Ammonia solution	(NH ₄) ₂ S	2*1,000 mL
Ammonium Persulfate	(NH ₄) ₂ S ₂ O ₈	4*1,000 g
Copper(II)sulfate anhydrous	CuSO ₄	2*250 g
Sodium sulfate anhydrous	NaSO ₄ .10H ₂ O	3*500 g
Azomethine H	C ₁₇ H ₁₂ NNaO ₈ S ₂	2 g
Bismuth sulfite	Bi ₂ (SO ₃) ₃	500 g
Bromocresol green	C ₂₁ H ₁₄ Br ₄ O ₅ S	5 g
Bromophenol Blue	C ₁₉ H ₁₀ Br ₄ O ₅ S	10 g
Chlorophenol red	C ₁₉ H ₁₂ Cl ₂ O ₅ S	5 g
Coomassie Brilliant Blue	C ₄₅ H ₄₄ N ₃ NaO ₇ S ₂	25 g
Copper Sulphate RPE	CuSO ₄ .5H ₂ O	2*1,000 g

Table A-5. (continued) Chemical substances used in SUT laboratories in year 1998.

Chemical substances category	Formula	Quantity
Sulfur Compounds		
o-Cresol red	$C_{21}H_{18}O_5S$	1*500 g
Dithiol	$CH_3C_6H_3(SH)_2$	1 g
Iron Sulfate	$FeSO_4$	500 g
Methyl sulphate	CH_4O_4S	25 mL
Nile blue A Color	$C_{20}H_{21}N_3O_5S$	2*50 g
Streptomycin,sulfate	$C_{42}H_{84}N_{14}O_{36}S_3$	100 mL
Phenol red	$C_{19}H_{14}O_5S$	1,005 g
Phosphoric Acid	H_2SO_4	6*1,000 mL
Potassium metabisulphite	$K_2S_2O_5$	2*1,000 g
Potassium persulfate	$K_2S_2O_8$	2*1,000 g
Potassium Pyrosulphite	$K_2S_2O_5$	1*1,000 g
Potassium sulphate	K_2SO_4	4*1,000 g
Quinine-Sulphate	$C_{40}H_{50}N_4O_8S$	25 g
sodium bisulphate	$NaHSO_4 \cdot H_2O$	500 g
Sodium ethylmercuriothiosalicylate	$C_9H_9HgNaO_2S$	5*1,000 g
Sodium pyruvate	$Na_2S_2O_7$	25 g
Sodium sulphate AR	Na_2SO_4	2*1,000 g
Sodium sulphite	Na_2SO_3	1*100 g
Sodium thiocyanate	$NaSCN$	100 g
sodium thiosulphate AR	$Na_2S_2O_3 \cdot 5H_2O$	3,500 g
Streptomysin sulfate Biochem	$C_{42}H_{84}O_{36}S_{32}$	25 g
Sulphamic acid	NH_2SO_3H	25*1,000 g
Sulphanilamide	$C_6H_8O_2N_2S$	500 g
Sulphuric acid	H_2SO_4	22.5*1,000 mL
Tartarzine	$C_{16}H_9N_4Na_3O_9S_2$	5*100 g
Taurine	$NH_2CH_2CH_2SO_3H$	5 g
Metals Compounds		
2,6-Dichlorophenolindophenol sodium salt	$NaOC_6H_4N:C_6H_2(Cl)_2:O \cdot 2H_2O$	5 g
Aluminium potassium sulfate	$AlK(SO_4)_2 \cdot 12H_2O$	5*500 g
Aluminium Sulphate AR RPE	$Al_2(SO_4)_3 \cdot 18H_2O$	1*1,000 g
Ammonium Metavanadate	NH_4VO_3	500 g
Copper(II)sulfate anhydrous	$CuSO_4$	2*250 g
Sodium sulfate anhydrous	$NaSO_4 \cdot 10H_2O$	3*500 g
A-nitrate AR	$Al(NO_3)_3 \cdot 9H_2O$	1*500 g
Azomethine H	$C_{17}H_{12}NNaO_8S_2$	2 g
Barium acetate	$Ba(CH_3COO)_2$	500 g
Barium carbonate	$BaCO_3$	1*1,000 g
Barium Chloride RPE	$BaCl_2 \cdot 2H_2O$	1*1,000 g
Barium Hydroxide	$Ba(OH)_2 \cdot 8H_2O$	1*1,000 g
Bismuth sulfite	$Bi_2(SO_3)_3$	500 g
zinc Acetate Dihydrate	$Zn(CH_3COO)_2 \cdot 2H_2O$	500 g
Zinc standard solution 1000mg/l	Zn	500 mL
Calcium carbonate-Commercial-	$CaBr_2 \cdot 2H_2O$	1*1,500 g

Table A-5. (continued) Chemical substances used in SUT laboratories in year 1998.

Chemical substances category	Formula	Quantity
Metals Compounds		
Calcium carbonate	CaBr ₂ .2H ₂ O	5,000 g
Calcium Chloride	CaCl ₂ .6H ₂ O	52*1,000 g
Calcium hypophosphite powder	Ca(H ₂ PO ₂) ₂	3*1,000 g
Calcium standard solution 1000mg/l	Ca	500 mL
Calcium Sulphate	CaSO ₄ .2H ₂ O	1*1,500 g
Chromium standard solution 1000mg/l	Cr	500 mL
Cobalt nitrate	Co(NO ₃) ₂ .6H ₂ O	250 g
Cobalt oxide	Co ₃ O ₄	500 g
Coomassie Brilliant Blue	C ₄₅ H ₄₄ N ₃ NaO ₇ S ₂	25 g
Copper oxide	Cu ₂ O	250 g
Copper standard solution 1000 mg/l	Cu	500 mL
Copper Sulphate RPE	CuSO ₄ .5H ₂ O	2*1,000 g
Chromic oxide	CrO ₃	1*1,000 g
Zinc standard solution 1000mg/l	Zn	500 mL
Diluted potassium hydroxide	KOH	1*1,000 g
di-Potassium hydrogen phosphate RPE	K ₂ HPO ₄	1,750 g
di-sodium hydrogen phosphate anhydrous	Na ₂ HPO ₄ .nH ₂ O	1,005 g
tri-Sodium phosphate	Na ₃ PO ₄ .12H ₂ O	1*500 g
EDTA disodium salt	[CH ₂ N(CH ₂ COOH)CH ₂ COONa] ₂ .2H ₂ O	3,100 g
Eosin-methylene blue	C ₂₀ H ₆ Br ₂ N ₂ Na ₂ O ₉	500 g
Iron standard Solution 1000 mg/l	Fe	500 mL
Iron Sulfate	FeSO ₄	500 g
Lead standard solution 1000 mg/l	Pb	500 mL
Lithium Chloride	LiCl	500 g
Magnesium carbonate	(MgCO ₃) ₄ .Mg(OH) ₂ .5H ₂ O	1*1,000 g
Magnesium oxide	MgO	1,100 g
Magnesium sulphate AR	MgSO ₄ .7H ₂ O	1*1,000 g
Manganese standard solution 1000mg/l	Mg	500 mL
Mercury(I)chloride	Hg ₂ Cl ₂	1.5*1,000 g
Methanol-d4 purum	CD ₃ OD	5 mL
Nickel nitrate	Ni(NO ₃) ₂ .6H ₂ O	250 g
Nickel oxide	NiO	100 g
Nickel standard solution 1000 mg/l	Ni	500 mL
Tartar emetic	C ₈ H ₁₀ K ₂ O ₁₅ Sb ₂	500 g
Potassium bromate	KBrO ₃	500 g
Potassium Carbonate	K ₂ CO ₃	1*1,000 g
Potassium Chloride	KCl	1*1,000 g
Potassium Dichromate	K ₂ Cr ₂ O ₇	1*1,000 g
Potassium dihydrogen phosphate	KH ₂ PO ₄	4*500 g
Potassium Hydroxide	KOH	1*1,000 g
Potassium iodate	KIO ₃	11.5*1,000 g
Potassium metabisulphite	K ₂ S ₂ O ₅	2*1,000 g
Potassium persulfate	K ₂ S ₂ O ₈	2*1,000 g

Table A-5. (continued) Chemical substances used in SUT laboratories in year 1998.

Chemical substances category	Formula	Quantity
Metals Compounds		
Potassium Pyrosulphite	$K_2S_2O_5$	1*1,000 g
Potassium sodium tartrate	$COOK(CHOH)_2COONa.4H_2O$	4.5*1,000 g
Potassium standard solution 1000 mg/l	K	500 mL
Potassium sulphate	K_2SO_4	4*1,000 g
Zinc sulfate	$ZnSO_4$	6*500 g
Zinc chloride	$ZnCl_2$	1*1,000 g
Sodium deuterioxide solution 40% in deuterium oxide	NaOD	25 g
Zinc oxide	ZnO	1*1,000 g
Silver bromate	$AgBrO_3$	305 g
Silver Nitrate	$AgNO_3$	450 g
Sodium acetate	$CH_3COONa.3H_2O$	4*250 g
Sodium Alginate	$(C_6H_7O_6Na)_n$	2*1,000 g
sodium bisulphate	$NaHSO_4.H_2O$	500 g
Sodium borohydride	$NaBH_4$	5,050 g
Sodium carbonate	Na_2CO_3	10*1,000 g
Sodium chromate	Na_2CrO_4	2,000 g
Sodium dihydrogen phosphate	$NaH_2PO_4.H_2O$	50 g
Sodium ethylmercuriothiosalicylate	$C_9H_9HgNaO_2S$	5*1,000 g
Sodium hexametaphosphate	$(NaPO_3)_6$	2,500 g
Sodium hydrogen carbonate	$NaHCO_3$	1*1,000 g
Sodium hydroxide	NaOH	23.5*1,000 g
Sodium hypochlorite	NaClO	1,000 mL
Sodium nitrate	$NaNO_3$	8.5*1,000 g
Sodium phosphate RPE-ACS	Na_3PO_4	4,000 g
Sodium pyruvate	$Na_2S_2O_7$	25 g
Sodium stannate	$Na_2SnO_3.3H_2O$	25 g
Sodium sulphate AR	Na_2SO_4	2,000 g
Sodium sulphite	Na_2SO_3	1*100 g
Sodium tartrate	$(CHOHCOONa)_2.2H_2O$	1*1,000 g
Sodium tetraborate decahydrate RPE		1*1,000 g
Sodium thiocyanate	NaSCN	100 g
sodium thiosulphate AR	$Na_2S_2O_3.5H_2O$	3,500 g
Sodium carbonate	Na_2CO_3	1*500 g
Standard Solution Sn	Sn	1*500 mL
Tantalum powder	Ta	27*1,000 g
Tartarazine	$C_{16}H_9N_4Na_3O_9S_2$	5*100 g
Zirconium(IV) oxide	ZrO_2	1*1,000 g
Tetrasodium pyrophosphate anhydrous	$Na_4P_2O_7.10H_2O$	1*1,000 g
tri-Sodium phosphate	$Na_3PO_4.12H_2O$	3*1,000 g

APPENDIX B

Isotherm Study

Table B-1. Isotherm study of acetic acid.

Initial acetic acid concentration 8.38 g/L., GAC=2/ L

Time (hr)	Effluent Concentration (g/L)	Amount of Acetic acid adsorbed (g)
24	9.35196	*
48	9.08412	*
72	7.96595	0.20808
96	8.28963	0.04623
120	8.86673	*
144	10.28697	*
168	8.43436	*
192	7.54138	0.42036
216	8.78326	*
240	7.54918	0.41646
264	7.42307	0.47951
288	8.98984	*
312	8.90036	*
336	8.92078	*
360	8.32686	0.02762
384	8.82710	*
408	8.75263	*
432	6.68263	0.84973
456	8.44997	*
504	8.87574	*

* Acetic acid wasn't adsorbed on GAC

Table B-2. Isotherm study of acetic acid.

Initial acetic acid concentration 8.38 g/L., GAC=4 /L

Time (hr)	Effluent Concentration (g/L)	Amount of Acetic acid adsorbed (g)
24	7.71493	0.33358
48	8.81689	*
72	7.89088	0.24561
96	8.12569	0.12821
120	8.57848	*
144	8.48420	*
168	7.89689	0.24261
192	7.37743	0.50233
216	7.17506	0.60352
240	7.44709	0.46750
264	7.42788	0.47711
288	8.89916	*
312	8.22898	0.07656
336	8.66856	*
360	8.07704	0.15253
384	8.62532	*
408	8.62892	*
432	8.31245	0.03482
456	9.46666	*
504	8.79587	*

Table B-3. Isotherm study of acetic acid.

Initial acetic acid concentration 8.38 g/L., GAC=6 /L

Time (hr)	Effluent Concentration (g/L)	Amount of Acetic acid adsorbed (g)
24	8.70940	*
48	8.82049	*
72	7.77858	0.30176
96	8.17553	0.10328
120	8.48900	*
144	8.58929	*
168	7.84164	0.27023
192	7.15884	0.61163
216	8.22117	0.08046
240	7.25553	0.56329
264	7.39665	0.49272
288	9.09193	*
312	8.62892	*
336	8.51422	*
360	8.48180	*
384	8.46979	*
408	8.48540	*
432	8.33227	0.02492
456	8.38751	*
504	7.78519	0.29845

Table B-4. Isotherm study of acetic acid.

Initial acetic acid concentration 8.38 g/L., GAC=8 /L

Time (hr)	Effluent Concentration (g/L)	Amount of Acetic acid adsorbed (g)
24	8.32326	0.02942
48	8.65535	*
72	7.66388	0.35911
96	8.34548	0.01831
120	8.29684	0.04263
144	8.27281	0.05464
168	8.00678	0.18766
192	7.94973	0.21618
216	7.08558	0.64826
240	6.99730	0.69240
264	7.18166	0.60022
288	6.74388	0.81911
312	8.38811	*
336	8.34187	0.02011
360	8.30404	0.03903
384	8.28963	0.04623
408	8.28062	0.05074
432	8.05422	0.16394
456	7.95754	0.21228
504	8.27041	0.05584

Table B-5. Isotherm study of acetic acid.

Initial acetic acid concentration 8.38 g/L., GAC=10 g/L

Time (hr)	Effluent Concentration (g/L)	Amount of Acetic acid adsorbed (g)
24	8.45237	*
48	8.54425	*
72	7.19848	0.59181
96	7.95033	0.21588
120	8.22057	0.08076
144	8.16472	0.10869
168	8.08245	0.14982
192	6.98589	0.69810
216	8.18153	0.10028
240	7.12101	0.63054
264	7.19848	0.59181
288	8.28723	0.04743
312	8.32266	0.02972
336	8.15271	0.11469
360	8.29143	0.04533
384	8.27462	0.05374
408	8.28603	0.04804
432	7.41046	0.48582
456	8.30524	0.03843
504	7.94793	0.21708

Table B-6. Isotherm study of acetic acid.

Initial acetic acid concentration 8.38 g/L., GAC=12 g/L

Time (hr)	Effluent Concentration (g/L)	Amount of Acetic acid adsorbed (g)
24	8.19955	0.09127
48	8.33587	0.02311
72	7.49153	0.44528
96	8.15932	0.11139
120	8.07164	0.15523
144	8.19655	0.09277
168	8.00858	0.18676
192	6.76069	0.81070
216	7.76537	0.30836
240	7.00090	0.69060
264	7.08258	0.64976
288	8.04401	0.16904
312	8.17613	0.10298
336	7.57861	0.40174
360	7.56119	0.41045
384	8.07044	0.15583
408	8.06083	0.16063
432	7.77078	0.30566
456	7.81882	0.28164
504	8.09206	0.14502

Table B-7. Isotherm study of acetic acid.

Initial acetic acid concentration 8.38 g/L., GAC=14 g/L

Time (hr)	Effluent Concentration (g/L)	Amount of Acetic acid adsorbed (g)
24	7.21289	0.58460
48	7.36302	0.50954
72	7.35581	0.51314
96	7.87527	0.25341
120	6.79853	0.79178
144	7.29516	0.54347
168	7.47532	0.45339
192	6.32051	1.03079
216	6.65260	0.86475
240	6.83816	0.77197
264	6.73067	0.82571
288	7.50534	0.43838
312	7.87226	0.25492
336	7.73595	0.32308
360	7.30957	0.53626
384	7.82302	0.27954
408	7.86986	0.25612
432	7.17145	0.60532
456	7.33720	0.52245
504	7.82482	0.27864

Table B-8. Isotherm study of acetic acid.

Initial acetic acid concentration 8.38 g/L., GAC=16 g/L

Time (hr)	Effluent Concentration (g/L)	Amount of Acetic acid adsorbed (g)
24	8.12148	0.13031
48	7.08918	0.64646
72	7.25613	0.56298
96	7.77678	0.30266
120	7.13002	0.62604
144	7.56179	0.41015
168	7.61584	0.38313
192	6.59795	0.89207
216	6.65500	0.86355
240	6.64119	0.87045
264	6.73547	0.82331
288	7.17686	0.60262
312	7.72934	0.32638
336	7.61764	0.38223
360	7.28315	0.54947
384	7.73535	0.32338
408	7.61704	0.38253
432	7.61704	0.38253
456	7.68190	0.35010
504	7.66929	0.35640

Table B-9. Isotherm study of ethyl acetate.

Initial ethyl acetate concentration 8.99 g/L., GAC=4 g/L

Time (hr)	Effluent Concentration (g/L)	Amount of Acetic acid adsorbed (g)
24	8.37148	0.30987
48	7.69852	0.64634
72	7.74328	0.62396
96	7.49861	0.74630
120	7.31808	0.83656
144	7.30425	0.84348
168	6.65861	1.16630
192	7.23649	0.87736
216	8.77861	0.10630
240	6.60460	1.19330
264	7.41482	0.78819
312	5.96812	1.51154
336	6.99447	0.99837
360	5.69975	1.64573
384	6.20283	1.39419

Table B-10. Isotherm study of ethyl acetate.

Initial ethyl acetate concentration 8.99 g/L., GAC=6 g/L

Time (hr)	Effluent Concentration (g/L)	Amount of Acetic acid adsorbed (g)
24	7.71544	0.63788
48	8.01015	0.49053
72	7.30627	0.84247
96	6.98513	1.00304
120	6.24512	1.37304
144	6.72240	1.13441
168	6.65588	1.16767
192	5.81076	1.59022
216	7.13297	0.92912
240	5.63288	1.67917
264	6.79341	1.09890
312	6.35676	1.31723
336	5.78636	1.60242
360	5.27182	1.85969
384	5.22715	1.88203

Table B-11. Isotherm study of ethyl acetate.

Initial ethyl acetate concentration 8.99 g/L., GAC=8 g/L

Time (hr)	Effluent Concentration (g/L)	Amount of Acetic acid adsorbed (g)
24	7.29597	0.84762
48	6.69605	1.14758
72	6.87949	1.05586
96	6.55464	1.21828
120	6.52028	1.23546
144	6.26574	1.36273
168	6.13129	1.42996
192	5.58081	1.70520
216	6.47376	1.25872
240	5.33023	1.83049
264	6.04169	1.47476
312	5.65367	1.66877
336	5.41050	1.79035
360	4.86820	2.06150
384	4.13287	2.42917

Table B-12. Isotherm study of ethyl acetate.

Initial ethyl acetate concentration 8.99 g/L., GAC=10 g/L

Time (hr)	Effluent Concentration (g/L)	Amount of Acetic acid adsorbed (g)
24	6.41808	1.28656
48	6.69182	1.14969
72	6.51394	1.23864
96	6.25561	1.36780
120	6.11059	1.44031
144	4.49913	2.24604
168	6.04504	1.47309
192	5.43481	1.77820
216	6.65367	1.16877
240	5.25226	1.86947
264	6.93729	1.02696
312	6.09667	1.44727
336	5.42371	1.78375
360	5.50574	1.74273
384	5.44230	1.77445

Table B-13. Isotherm study of ethyl acetate.

Initial ethyl acetate concentration 8.99 g/L., GAC=12 g/L

Time (hr)	Effluent Concentration (g/L)	Amount of Acetic acid adsorbed (g)
24	6.39173	1.29974
48	6.05913	1.46604
72	5.22900	1.88110
96	5.54891	1.72115
120	5.52697	1.73212
144	5.64266	1.67428
168	5.46160	1.76480
192	4.19490	2.39815
216	4.68107	2.15507
240	4.90917	2.04102
264	4.52142	2.23489
312	4.48036	2.25542
336	3.71551	2.63785
360	3.90635	2.54243
384	4.38917	2.30102

Table B-14. Isotherm study of ethyl acetate.

Initial ethyl acetate concentration 8.99 g/L., GAC=14 g/L

Time (hr)	Effluent Concentration (g/L)	Amount of Acetic acid adsorbed (g)
24	5.96900	1.51110
48	4.95050	2.02036
72	5.18583	1.90269
96	5.02530	1.98295
120	4.93931	2.02595
144	4.50327	2.24397
168	4.79155	2.09983
192	3.35225	2.81948
216	5.05032	1.97044
240	3.66256	2.66432
264	6.24477	1.37322
312	4.36776	2.31172
336	4.19226	2.39948
360	3.78397	2.60362
384	3.32564	2.83278

Table B-15. Isotherm study of ethyl acetate.

Initial ethyl acetate concentration 8.99 g/L., GAC=16 g/L

Time (hr)	Effluent Concentration (g/L)	Amount of Acetic acid adsorbed (g)
24	5.48847	1.75137
48	5.06433	1.96344
72	4.79640	2.09740
96	4.53217	2.22952
120	4.26177	2.36472
144	4.47067	2.26027
168	3.87904	2.55608
192	2.73815	3.12653
216	4.59560	2.19780
240	3.21763	2.88679
264	3.64556	2.67282
312	3.43560	2.77780
336	3.08415	2.95353
360	2.96890	3.01115
384	3.65023	2.67049

APPENDIX C

Data of Breakthrough Curve for Acetic acid

Table C-1. Carbon adsorption breakthrough curve of acetic acid. Influent concentration (C_{in}) = 0.14 M, GAC = 400 g

No.	Initial time	Time usage (min.)	Flow rate (ml/min.)	Average flow rate (ml/min.)	Volume of water treated (ml)	Cumulative volume of water treated (ml)	Effluent conc. (M) C_{out}	C_{out}/C_{in}
	13:25		17.0					
	13:28	3	22.0	19.50	58.50	58.50		
1	13:35	7	21.0	21.50	150.50	209.00	0.00126	0.00908
2	13:40	5	20.0	20.50	102.50	311.50	0.00255	0.01832
3	13:50	10	18.0	19.00	190.00	501.50	0.00310	0.02222
4	14:00	10	16.0	17.00	170.00	671.50		
5	14:10	10	16.0	16.00	160.00	831.50	0.01031	0.07392
6	14:20	10	15.5	15.75	157.50	989.00	0.01173	0.08408
7	14:30	10	15.0	15.25	152.50	1141.50	0.01014	0.07268
8	14:40	10	14.0	14.50	145.00	1286.50	0.00997	0.07143
9	14:50	10	14.0	14.00	140.00	1426.50	0.00896	0.06421
10	15:00	10	14.0	14.00	140.00	1566.50	0.00870	0.06232
11	15:10	10	12.5	13.25	132.50	1699.00	0.00848	0.06080
12	15:20	10	12.0	12.25	122.50	1821.50	0.00851	0.06101
13	15:30	10	12.0	12.00	120.00	1941.50	0.00893	0.06403
14	15:40	10	11.0	11.50	115.00	2056.50	0.00872	0.06249
15	15:50	10	10.5	10.75	107.50	2164.00	0.00894	0.06404
16	16:00	10	10.0	10.25	102.50	2266.50	0.01075	0.07701
	17:16	6	12.0	11.00	66.00	2332.50		
17	17:20	4	12.0	12.00	48.00	2380.50	0.01059	0.07591
18	17:30	10	11.0	11.50	115.00	2495.50	0.01454	0.10420
19	17:40	10	10.0	10.50	105.00	2600.50	0.01174	0.08415
20	17:47	7	9.0	9.50	66.50	2667.00	0.01116	0.08000
	11:12	5	22.5		0.00			
21	11:20	8	19.0	20.75	166.00	2833.00	0.01472	0.10549
22	11:30	10	17.0	18.00	180.00	3013.00	0.01078	0.07723
23	11:40	10	15.5	16.25	162.50	3175.50	0.01137	0.08151

Table C-1. (continued) Carbon adsorption breakthrough curve of acetic acid. Influent concentration (C_{in}) = 0.14 M, GAC = 400 g.

No.	Initial time	Time usage	Flow rate	Average flow rate	Volume of water	Cumulative volume of	Effluent conc. (M)	C_{out}/C_{in}
		(min.)	(ml/min.)	(ml/min.)	treated (ml)	water treated (ml)	C_{out}	
24	11:50	10	13.0	14.25	142.50	3318.00	0.01886	0.13512
25	12:00	10	11.0	12.00	120.00	3438.00	0.02766	0.19820
26	12:10	10	10.0	10.50	105.00	3543.00	0.03567	0.25556
27	12:20	10	9.5	9.75	97.50	3640.50	0.04719	0.33815
	12:23	3	18.0	9.50	28.50	3669.00		
28	12:30	7	16.0	17.00	119.00	3788.00	0.06308	0.45194
29	12:40	10	15.5	15.75	157.50	3945.50	0.09215	0.66021
30	12:50	10	15.0	15.25	152.50	4098.00	0.10753	0.77038
31	13:00	10	14.0	14.50	145.00	4243.00	0.11913	0.85348
32	13:10	10	14.0	14.00	140.00	4383.00	0.13422	0.96159
	14:40	10	39.5		0.00			
	14:50	10	35.0	37.25	372.50	4755.50		
33	15:00	10	32.5	33.75	337.50	5093.00	0.15225	1.09077
	15:10	10	30.0	31.25	312.50	5405.50		
34	15:20	10	28.0	29.00	290.00	5695.50	0.16012	1.14715
	15:30	10	27.0	27.50	275.00	5970.50		
35	15:40	10	26.0	26.50	265.00	6235.50	0.15576	1.11591
	15:50	10	24.0	25.00	250.00	6485.50		
36	16:00	10	23.0	23.50	235.00	6720.50	0.16629	1.19136
	16:10	10	21.0	22.00	220.00	6940.50		
	16:20	10	20.0	20.50	205.00	7145.50		
37	16:30	10	19.5	19.75	197.50	7343.00	0.17129	1.22718
	16:40	10	18.0	18.75	187.50	7530.50		
	16:50	10	16.0	17.00	170.00	7700.50		
38	17:00	10	15.0	15.50	155.00	7855.50	0.17371	1.24451
	17:10	10	13.5	14.25	142.50	7998.00		
	17:20	10	12.0	12.75	127.50	8125.50		

Table C-1. (continued) Carbon adsorption breakthrough curve of acetic acid. Influent concentration (C_{in}) = 0.14 M, GAC = 400 g.

No.	Initial time	Time usage	Flow rate	Average flow rate	Volume of water	Cumulative volume of	Effluent conc. (M)	C_{out}/C_{in}
		(min.)	(ml/min.)	(ml/min.)	treated (ml)	water treated (ml)	C_{out}	
39	17:30	10	10.0	11.00	110.00	8235.50	0.17394	1.24616
	17:40	10	9.0	9.50	95.00	8330.50		
	17:41	1	13.0	9.00	9.00	8339.50		
	17:50	9	12.0	12.50	112.50	8452.00		
40	18:00	10	11.0	11.50	115.00	8567.00	0.17251	1.23592
	11:10	10	21.5		0.00			
	11:20	10	19.0	20.25	202.50	8769.50		
	11:30	10	18.0	18.50	185.00	8954.50		
41	11:40	10	18.0	18.00	180.00	9134.50		
	11:50	10	14.0	16.00	160.00	9294.50		
42	12:00	10	13.5	13.75	137.50	9432.00	0.17703	1.26830
	12:10	10	12.0	12.75	127.50	9559.50		
	12:20	10	11.5	11.75	117.50	9677.00		
43	12:30	10	11.0	11.25	112.50	9789.50	0.16998	1.21779
	12:40	10	11.0	11.00	110.00	9899.50		
	12:50	10	10.5	10.75	107.50	10007.00		
44	13:00	10	10.5	10.50	105.00	10112.00	0.16667	1.19408
	13:10	10	10.0	10.25	102.50	10214.50		
	13:20	10	10.0	10.00	100.00	10314.50		
45	13:30	10	9.5	9.75	97.50	10412.00	0.16470	1.17996
	13:40	10	9.0	9.25	92.50	10504.50		
	13:50	10	8.5	8.75	87.50	10592.00		
46	14:00	10	8.0	8.25	82.50	10674.50	0.16297	1.16757
	14:03	3	9.0	8.50	25.50	10700.00		
	14:10	7	9.0	9.00	63.00	10763.00		
	14:20	10	9.0	9.00	90.00	10853.00		
47	14:30	10	9.0	9.00	90.00	10943.00	0.16364	1.17237

Table C-1. (continued) Carbon adsorption breakthrough curve of acetic acid. Influent concentration (C_{in}) = 0.14 M, GAC = 400 g.

No.	Initial time	Time usage (min.)	Flow rate (ml/min.)	Average flow rate (ml/min.)	Volume of water treated (ml)	Cumulative volume of water treated (ml)	Effluent conc. (M) C_{out}	C_{out}/C_{in}
48	14:45	15	8.5	8.75	131.25	11074.25	0.15851	1.13562
	14:50	5	8.0	8.25	41.25	11115.50		
	15:00	10	8.0	8.00	80.00	11195.50		
	15:10	10	31.0	8.00	80.00	11275.50		
49	15:20	10	29.0	30.00	300.00	11575.50	0.14622	1.04757
	15:30	10	26.5	27.75	277.50	11853.00		
	15:40	10	26.0	26.25	262.50	12115.50		
50	15:50	10	24.0	25.00	250.00	12365.50	0.14319	1.02586
	16:00	10	24.0	24.00	240.00	12605.50		
	16:10	10	22.5	23.25	232.50	12838.00		
50	16:20	10	22.5	22.50	225.00	13063.00	0.14206	1.01776
	16:30	10	22.0	22.25	222.50	13285.50		
	16:40	10	20.5	21.25	212.50	13498.00		
51	16:50	10	20.0	20.25	202.50	13700.50	0.13944	0.99899
	17:00	10	19.5	19.75	197.50	13898.00		
	17:10	10	38.0	19.50	195.00	14093.00		
52	17:20	10	35.0	36.50	365.00	14458.00	0.13916	0.99699
	17:30	10	33.0	34.00	340.00	14798.00		
	17:40	10	29.0	31.00	310.00	15108.00		
53	17:50	10	27.0	28.00	280.00	15388.00	0.13797	0.98846
	18:00	10	24.0	25.50	255.00	15643.00		
	8:05	5	17.5		0.00			
54	8:20	15	14.0	15.75	236.25	15879.25	0.13821	0.99018
	8:30	10	12.5	13.25	132.50	16011.75		
	8:40	10	11.5	12.00	120.00	16131.75		
	8:50	10	10.0	10.75	107.50	16239.25		
55	9:00	10	8.5	9.25	92.50	16331.75	0.13439	0.96281

Table C-1. (continued) Carbon adsorption breakthrough curve of acetic acid. Influent concentration (C_{in}) = 0.14 M, GAC = 400 g.

No.	Initial time	Time usage	Flow rate	Average flow rate	Volume of water	Cumulative volume of	Effluent conc. (M)	C_{out}/C_{in}
		(min.)	(ml/min.)	(ml/min.)	treated (ml)	water treated (ml)	C_{out}	
56	9:15	15	25.5	8.50	127.50	16459.25	0.13561	0.97155
	9:20	5	24.5	25.00	125.00	16584.25		
	9:25	5	23.0	23.75	118.75	16703.00		
	9:30	5	23.0	23.00	115.00	16818.00		
	9:35	5	21.5	22.25	111.25	16929.25		
	9:40	5	20.0	20.75	103.75	17033.00		
	9:50	10	17.0	18.50	185.00	17218.00		
	10:00	10	16.0	16.50	165.00	17383.00		
	10:10	10	15.5	15.75	157.50	17540.50		
	10:20	10	15.0	15.25	152.50	17693.00		
57	10:30	10	14.0	14.50	145.00	17838.00	0.13860	0.99297
	10:40	10	13.0	13.50	135.00	17973.00		
	10:50	10	12.5	12.75	127.50	18100.50		
	11:00	10	12.0	12.25	122.50	18223.00		
	11:10	10	12.0	12.00	120.00	18343.00		
	11:20	10	10.0	11.00	110.00	18453.00		
	11:30	10	9.0	9.50	95.00	18548.00		
	11:31	1	32.0	9.00	9.00	18557.00		
	11:35	4	31.5	31.75	127.00	18684.00		
	11:45	10	30.0	30.75	307.50	18991.50		
58	11:50	5	29.0	29.50	147.50	19139.00	0.13675	0.97972
	11:55	5	28.0	28.50	142.50	19281.50		
	12:00	5	27.0	27.50	137.50	19419.00		
	12:10	10	25.0	26.00	260.00	19679.00		
	12:15	5	24.0	24.50	122.50	19801.50		
	12:20	5	23.5	23.75	118.75	19920.25		
	12:25	5	23.0	23.25	116.25	20036.50		

Table C-1. (continued) Carbon adsorption breakthrough curve of acetic acid. Influent concentration (C_{in}) = 0.14 M, GAC = 400 g.

No.	Initial time	Time usage (min.)	Flow rate (ml/min.)	Average flow rate (ml/min.)	Volume of water treated (ml)	Cumulative volume of water treated (ml)	Effluent conc. (M) C_{out}	C_{out}/C_{in}
59	12:30	5	22.0	22.50	112.50	20149.00	0.13361	0.95722
	12:35	5	21.0	21.50	107.50	20256.50		
	12:40	5	20.0	20.50	102.50	20359.00		
	12:45	5	18.5	19.25	96.25	20455.25		
	12:50	5	18.0	18.25	91.25	20546.50		
	12:55	5	17.0	17.50	87.50	20634.00		
	13:00	5	16.0	16.50	82.50	20716.50		
	7:15	0	48.0	0.00				
60	15:30	15	45.5	46.75	701.25	21417.75	0.11757	0.84231
61	15:45	15	50.0	45.50	682.50	22100.25	0.11786	0.84439
62	16:00	15	49.0	49.50	742.50	22842.75	0.11633	0.83342
63	16:15	15	47.5	48.25	723.75	23566.50	0.11612	0.83192
64	16:30	15	41.0	44.25	663.75	24230.25	0.11626	0.83292
65	16:45	15	43.2	41.00	615.00	24845.25	0.11777	0.84374
66	17:00	15	40.5	41.83	627.38	25472.63	0.11227	0.80434
67	17:15	15	39.0	39.75	596.25	26068.88	0.11741	0.84116
	7:00		45.5	0.00				
68	7:10	10	41.0	43.25	432.50	26501.38	0.13191	0.94504
69	7:20	10	40.0	40.50	405.00	26906.38	0.11962	0.85700
70	7:30	10	37.0	38.50	385.00	27291.38	0.11457	0.82082
71	7:40	10	37.0	37.00	370.00	27661.38	0.13897	0.99563
72	7:50	10	36.0	36.50	365.00	28026.38	0.13249	0.94920
73	8:00	10	35.0	35.50	355.00	28381.38	0.13956	0.99985
74	8:10	10	31.0	33.00	330.00	28711.38	0.14245	1.02056
75	8:20	10	31.0	31.00	310.00	29021.38	0.13279	0.95135
76	8:30	10	29.5	30.25	302.50	29323.88	0.16267	1.16542
77	8:40	10	29.5	29.50	295.00	29618.88	0.13139	0.94132

Table C-1. (continued) Carbon adsorption breakthrough curve of acetic acid. Influent concentration (C_{in}) = 0.14 M, GAC = 400 g.

No.	Initial time	Time usage	Flow rate	Average flow rate	Volume of water	Cumulative volume of	Effluent conc. (M)	C_{out}/C_{in}
		(min.)	(ml/min.)	(ml/min.)	treated (ml)	water treated (ml)	C_{out}	
78	8:50	10	28.0	28.75	287.50	29906.38	0.14321	1.02600
79	9:00	10	26.0	27.00	270.00	30176.38	0.13909	0.99648
80	9:20	10	26.0	26.00	260.00	30436.38	0.13967	1.00064
81	9:30	10	25.0	25.50	255.00	30691.38	0.15478	1.10889
82	9:40	10	24.5	24.75	247.50	30938.88	0.15958	1.14328
83	9:50	10	23.0	23.75	237.50	31176.38	0.14208	1.01791
84	10:00	10	23.0	23.00	230.00	31406.38	0.13957	0.99992
85	10:10	10	22.5	22.75	227.50	31633.88	0.13989	1.00222
86	10:20	10	21.5	22.00	220.00	31853.88	0.14196	1.01705
87	10:30	10	21.0	21.25	212.50			
88	10:40	10	19.0	20.00	200.00	32053.88	0.12535	0.89805
89	10:50	10	18.5	18.75	187.50	32241.38	0.14122	1.01175
90	11:00	10	18.0	18.25	182.50	32236.38	0.14078	1.00859
91	11:10	10	17.0	17.50	175.00	32416.38	0.13959	1.00007
92	11:20	10	16.0	16.50	165.00	32401.38	0.13979	1.00150
93	11:30	10	15.5	15.75	157.50	32573.88	0.13970	1.00086
94	11:40	10	15.0	15.25	152.50	32553.88	0.14045	1.00623
95	11:50	10	14.0	14.50	145.00	32718.88	0.12638	0.90543
96	12:00	10	14.0	14.00	140.00	32693.88	0.14045	1.00623
97	12:10	10	13.0	13.50	135.00	32853.88	0.14906	1.06791
	12:40	10	10.5	11.75				
98	12:50	10	10.5	10.50	105.00	32958.88	0.14047	1.00637
	12:55	5	27.0	10.50				
99	13:00	5	24.5	25.75	128.75	33087.63	0.13774	0.98681
	13:05	5	38.0	24.50				
100	13:10	5	30.5	34.25	171.25	33258.88	0.12408	0.88895
101	13:20	10	30.5	30.50	305.00	33563.88	0.15958	1.14328

Table C-1. (continued) Carbon adsorption breakthrough curve of acetic acid. Influent concentration (C_{in}) = 0.14 M, GAC = 400 g.

No.	Initial time	Time usage (min.)	Flow rate (ml/min.)	Average flow rate (ml/min.)	Volume of water treated (ml)	Cumulative volume of water treated (ml)	Effluent conc. (M) C_{out}	C_{out}/C_{in}
102	13:30	10	30.5	30.50	305.00	33868.88	0.13888	0.99498
103	13:40	10	29.5	30.00	300.00	34168.88	0.13998	1.00286
104	13:55	10	29.0	29.25	292.50	34461.38	0.13993	1.00250
105	14:00	10	29.0	29.00	290.00	34751.38	0.12661	0.90707
106	14:10	10	26.3	27.65	276.50	35027.88	0.14225	1.01912
107	14:20	10	26.3	26.30	263.00	35290.88	0.14712	1.05401
108	14:30	10	25.7	26.00	260.00	35550.88	0.14646	1.04929
109	14:40	10	25.0	25.35	253.50	35804.38	0.14568	1.04370
110	14:50	10	24.0	24.50	245.00	36049.38	0.16246	1.16392
111	15:00	10	23.5	23.75	237.50	36286.88	0.14651	1.04964
112	15:10	10	23.0	23.25	232.50	36519.38	0.14105	1.01053
113	15:20	10	22.0	22.50	225.00	36744.38	0.14644	1.04914
114	15:30	10	22.0	22.00	220.00	36964.38	0.14111	1.01096
115	15:40	10	22.0	22.00	220.00	37184.38	0.14923	1.06913
116	15:50	10	21.0	21.50	215.00	37399.38	0.14081	1.00881
117	16:00	10	20.2	20.60	206.00	37605.38	0.14190	1.01662
118	16:10	10	33.0	20.20	202.00	37807.38	0.14450	1.03524
119	16:20	10	33.0	33.00	330.00	38137.38	0.14034	1.00544
120	16:30	10	31.5	32.25	322.50	38459.88	0.14288	1.02364
121	16:40	10	31.0	31.25	312.50	38772.38	0.14112	1.01103
122	16:50	10	29.5	30.25	302.50	39074.88	0.13910	0.99656
123	17:00	10	28.5	29.00	290.00	39364.88	0.14122	1.01175
	18:34		57.5	28.50				
124	18:40	6	54.0	55.75	334.50	39699.38	0.12569	0.90048
	18:44	6	25.0	54.00				
125	18:50	6	23.5	24.25	145.50	39844.88	0.14130	1.01232
126	19:00	10	23.0	23.25	232.50	40077.38	0.14290	1.02378

Table C-1. (continued) Carbon adsorption breakthrough curve of acetic acid. Influent concentration (C_{in}) = 0.14 M, GAC = 400 g.

No.	Initial time	Time usage	Flow rate	Average flow rate	Volume of water	Cumulative volume of	Effluent conc. (M)	C_{out}/C_{in}
		(min.)	(ml/min.)	(ml/min.)	treated (ml)	water treated (ml)	C_{out}	
127	19:10	10	21.0	22.00	220.00	40297.38	0.14232	1.01963
128	19:20	10	20.0	20.50	205.00	40502.38	0.13860	0.99297
129	19:30	10	19.0	19.50	195.00	40697.38	0.13935	0.99835
130	19:40	10	17.5	18.25	182.50	40879.88	0.13890	0.99512
131	19:50	10	15.0	16.25	162.50	41042.38	0.14023	1.00465
	19:55	6	21.0	15.00				
132	20:00	5	19.5	20.25	101.25	41143.63	0.13824	0.99040
133	20:10	10	18.0	18.75	187.50	41331.13	0.13694	0.98108
134	20:20	10	17.0	17.50	175.00	41506.13	0.12418	0.88966
	6:40		32.5	0.00				
135	6:50	10	28.5	30.50	305.00	41811.13	0.13690	0.98080
136	7:00	10	23.0	25.75	257.50	42068.63	0.13462	0.96446
137	7:10	10	20.0	21.50	215.00	42026.13	0.14329	1.02658
138	7:20	10	20.0	20.00	200.00	42268.63	0.13807	0.98918
139	7:30	10	20.0	20.00	200.00	42226.13	0.13868	0.99355
140	7:40	10	18.5	19.25	192.50	42461.13	0.14821	1.06182
141	7:50	10	18.5	18.50	185.00	42411.13	0.13665	0.97900
142	8:00	10	18.5	18.50	185.00	42646.13	0.14134	1.01260
143	8:10	10	18.5	18.50	185.00	42596.13	0.14111	1.01096
144	8:20	10	18.0	18.25	182.50	42828.63	0.13806	0.98911
145	8:30	10	17.0	17.50	175.00	42771.13	0.13888	0.99498
146	8:40	10	17.0	17.00	170.00	42998.63	0.13806	0.98911
147	8:50	10	16.0	16.50	165.00	42936.13	0.13791	0.98803
148	9:00	10	15.5	15.75	157.50	43156.13	0.13963	1.00035
149	9:10	10	15.0	15.25	152.50	43088.63	0.14068	1.00788
	10:45		29.0	0.00				
150	10:50	5	20.0	24.50	122.50	43211.13	0.11591	0.83042

Table C-1. (continued) Carbon adsorption breakthrough curve of acetic acid. Influent concentration (C_{in}) = 0.14 M, GAC = 400 g.

No.	Initial time	Time usage	Flow rate	Average flow rate	Volume of water	Cumulative volume of	Effluent conc. (M)	C_{out}/C_{in}
		(min.)	(ml/min.)	(ml/min.)	treated (ml)	water treated (ml)	C_{out}	
151	11:00	10	19.0	19.50	195.00	43406.13	0.11925	0.85434
152	11:10	10	18.0	18.50	185.00	43591.13	0.12676	0.90815
153	11:20	10	17.5	17.75	177.50	43768.63	0.13218	0.94698
154	11:30	10	16.5	17.00	170.00	43938.63	0.13685	0.98044
155	11:40	10	15.0	15.75	157.50	44096.13	0.13676	0.97979
156	11:50	10	14.5	14.75	147.50	44243.63	0.13936	0.99842
157	12:00	10	13.0	13.75	137.50	44381.13	0.13893	0.99534
158	12:02	2	18.5	13.00				
	12:10	8	17.0	17.75	142.00	44523.13	0.13985	1.00193
159	12:12	2	26.0	17.00				
	12:20	8	15.0	20.50	164.00	44687.13	0.14224	1.01905
160	12:25	5	42.0	15.00				
	12:30	5	39.0	40.50	202.50	44889.63	0.14274	1.02263
161	12:40	10	31.0	35.00	350.00	45239.63	0.14515	1.03990
162	12:50	10	27.5	29.25	292.50	45532.13	0.14684	1.05201
	7:17		35.5	0.00				
163	7:30	13	32.0	33.75	438.75	45970.88	0.12993	0.93086
164	7:40	10	29.0	30.50	305.00	46275.88	0.14376	1.02994
165	7:50	10	27.0	28.00	280.00	46250.88	0.15540	1.11334
166	8:00	10	25.0	26.00	260.00	46535.88	0.13919	0.99720
167	8:10	10	24.5	24.75	247.50	46498.38	0.15646	1.12093
168	8:20	10	22.5	23.50	235.00	46770.88	0.14091	1.00952
169	8:30	10	22.5	22.50	225.00	46723.38	0.14949	1.07099
170	8:40	10	20.5	21.50	215.00	46985.88	0.14173	1.01540
171	8:50	10	18.0	19.25	192.50	46915.88	0.14223	1.01898
172	9:00	10	17.5	17.75	177.50	47163.38	0.15843	1.13504
173	9:10	10	15.0	16.25	162.50	47078.38	0.15987	1.14536

Table C-1. (continued) Carbon adsorption breakthrough curve of acetic acid. Influent concentration (C_{in}) = 0.14 M, GAC = 400 g.

No.	Initial time	Time usage	Flow rate	Average flow rate	Volume of water	Cumulative volume of	Effluent conc. (M)	C_{out}/C_{in}
		(min.)	(ml/min.)	(ml/min.)	treated (ml)	water treated (ml)	C_{out}	
174	9:20	10	15.0	15.00	150.00	47313.38	0.14205	1.01769
175	9:30	10	14.0	14.50	145.00	47223.38	0.14226	1.01920
176	9:40	10	11.0	12.50	125.00	47438.38	0.14974	1.07279
177	9:50	10	10.0	10.50	105.00	47328.38	0.14149	1.01368
	9:54	6	25.0	10.00				
178	10:00	6	17.5	21.25	127.50	47455.88	0.14070	1.00802
179	10:10	10	13.5	15.50	155.00	47610.88	0.14099	1.01010
	10:15	5	25.0	13.50				
180	10:20	5	20.5	22.75	113.75	47724.63	0.14084	1.00902
181	10:30	10	19.0	19.75	197.50	47922.13	0.13824	0.99040
182	10:40	10	19.0	19.00	190.00	48112.13	0.15364	1.10073
183	10:50	10	18.0	18.50	185.00	48297.13	0.13482	0.96589
184	11:00	10	17.0	17.50	175.00	48472.13	0.13426	0.96188
185	11:10	10	17.0	17.00	170.00	48642.13	0.13359	0.95708
186	11:20	10	17.0	17.00	170.00	48812.13	0.13164	0.94311
187	11:30	10	16.0	16.50	165.00	48977.13	0.13252	0.94942
188	11:40	10	16.0	16.00	160.00	49137.13	0.11741	0.84116
189	11:50	10	15.0	15.50	155.00	49292.13	0.13548	0.97062
190	12:00	10	13.5	14.25	142.50	49434.63	0.13216	0.94684
191	12:10	10	14.5	13.50	135.00	49569.63	0.13258	0.94985
192	12:20	10	13.5	14.00	140.00	49709.63	0.13184	0.94454
193	12:30	10	13.0	13.25	132.50	49842.13	0.13160	0.94282
194	12:40	10	13.0	13.00	130.00	49972.13	0.13124	0.94024
195	12:50	10	12.5	12.75	127.50	50099.63	0.13209	0.94633
	13:17		51.5			50099.63		
	13:20	3	48.5	50.00	150.00	50249.63		
	13:25	5	48.0	48.25	241.25	50490.88		

Table C-1. (continued) Carbon adsorption breakthrough curve of acetic acid. Influent concentration (C_{in}) = 0.14 M, GAC = 400 g.

No.	Initial time	Time usage	Flow rate	Average flow rate	Volume of water	Cumulative volume of	Effluent conc. (M)	C_{out}/C_{in}
		(min.)	(ml/min.)	(ml/min.)	treated (ml)	water treated (ml)	C_{out}	
195	13:30	5	48.0	48.00	240.00	50730.88	0.12272	0.87920
	13:35	5	45.0	46.50	232.50	50963.38		
	13:40	5	43.5	44.25	221.25	51184.63		
	13:45	5	41.5	42.50	212.50	51397.13		
	13:50	5	40.0	40.75	203.75	51600.88		
	13:55	5	38.0	39.00	195.00	51795.88		
196	14:00	5	38.0	38.00	190.00	51985.88	0.13770	0.98653
	14:05	5	36.0	37.00	185.00	52170.88		
	14:10	5	35.0	35.50	177.50	52348.38		
	14:15	5	33.0	34.00	170.00	52518.38		
	14:20	5	33.0	33.00	165.00	52683.38		
	14:25	5	30.5	31.75	158.75	52842.13		
197	14:30	5	30.0	30.25	151.25	52993.38	0.13909	0.99648
	14:35	5	29.0	29.50	147.50	53140.88		
	14:40	5	28.0	28.50	142.50	53283.38		
	14:45	5	27.0	27.50	137.50	53420.88		
	14:46	5	41.0			53420.88		
	14:50	5	40.0	40.50	202.50	53623.38		
198	14:55	5	38.0	39.00	195.00	53818.38	0.14010	1.00372
	15:00	5	37.0	37.50	187.50	54005.88		
	15:05	5	33.5	35.25	176.25	54182.13		
	15:10	5	31.0	32.25	161.25	54343.38		
	15:15	5	28.5	29.75	148.75	54492.13		
	15:20	5	27.5	28.00	140.00	54632.13		
199	15:25	5	23.0	25.25	126.25	54758.38	0.14175	1.01554
	15:30	5	21.0	22.00	110.00	54868.38		
	15:34	5	46.0		0.00	54868.38		

Table C-1. (continued) Carbon adsorption breakthrough curve of acetic acid. Influent concentration (C_{in}) = 0.14 M, GAC = 400 g.

No.	Initial time	Time usage	Flow rate	Average flow rate	Volume of water	Cumulative volume of	Effluent conc. (M)	C_{out}/C_{in}
		(min.)	(ml/min.)	(ml/min.)	treated (ml)	water treated (ml)	C_{out}	
200	15:40	5	44.0	45.00	225.00	55093.38	0.14059	1.00723
	15:45	5	41.0	42.50	212.50	55305.88		
	15:50	5	41.0	41.00	205.00	55510.88		
	15:55	5	39.0	40.00	200.00	55710.88		
	16:00	5	37.5	38.25	191.25	55902.13		
	16:05	5	37.5	37.50	187.50	56089.63		
	16:10	5	37.0	37.25	186.25	56275.88		
	16:15	5	36.0	36.50	182.50	56458.38		
201	16:20	5	35.0	35.50	177.50	56635.88	0.13976	1.00129
	16:25	5	33.0	34.00	170.00	56805.88		
	16:30	5	32.0	32.50	162.50	56968.38		
	16:35	5	31.0	31.50	157.50	57125.88		
	16:40	5	31.0	31.00	155.00	57280.88		
	16:45	5	30.0	30.50	152.50	57433.38		
	16:50	5	28.0	29.00	145.00	57578.38		
	16:55	5	28.0	28.00	140.00	57718.38		
202	17:00	5	27.5	27.75	138.75	57857.13	0.14258	1.02149
	17:02	2	42.0		0.00	57857.13		
	17:05	5	40.5	41.25	206.25	58063.38		
	17:10	5	38.0	39.25	196.25	58259.63		
	17:15	5	37.0	37.50	187.50	58447.13		
	17:20	5	35.0	36.00	180.00	58627.13		
	17:25	5	33.5	34.25	171.25	58798.38		
	17:30	5	31.0	32.25	161.25	58959.63		
203	7:03	5	31.0	31.00	155.00	59114.63	0.13938	0.99856
	7:05	5	84.0		0.00	59114.63		
	7:10	5	78.0	81.00	405.00	59519.63		

Table C-1. (continued) Carbon adsorption breakthrough curve of acetic acid. Influent concentration (C_{in}) = 0.14 M, GAC = 400 g.

No.	Initial time	Time usage	Flow rate	Average flow rate	Volume of water	Cumulative volume of	Effluent conc. (M)	C_{out}/C_{in}
		(min.)	(ml/min.)	(ml/min.)	treated (ml)	water treated (ml)	C_{out}	
204	7:15	5	76.0	77.00	385.00	59904.63	0.13839	0.99147
	7:20	5	76.0	76.00	380.00	60284.63		
	7:25	5	71.0	73.50	367.50	60652.13		
	7:30	5	70.0	70.50	352.50	61004.63		
	7:35	5	66.0	68.00	340.00	61344.63		
	7:40	5	63.0	64.50	322.50	61667.13		
	7:45	5	60.0	61.50	307.50	61974.63		
205	7:50	5	58.0	59.00	295.00	62269.63	0.13873	0.99391
	7:55	5	54.0	56.00	280.00	62549.63		
	8:00	5	53.0	53.50	267.50	62817.13		
	8:05	5	50.0	51.50	257.50	63074.63		
	8:10	5	46.0	48.00	240.00	63314.63		
	8:15	5	42.0	44.00	220.00	63534.63		
	8:20	5	40.0	41.00	205.00	63739.63		
206	8:25	5	37.0	38.50	192.50	63932.13	0.14113	1.01110
	8:30	5	24.0	30.50	152.50	64084.63		
	8:35	5	100.0		0.00	64084.63		
	8:40	5	100.0	100.00	500.00	64584.63		
	8:45	5	95.0	97.50	487.50	65072.13		
	8:50	5	91.0	93.00	465.00	65537.13		
	8:55	5	88.0	89.50	447.50	65984.63		
207	9:00	5	80.0	84.00	420.00	66404.63	0.13956	0.99985
	9:05	5	77.0	78.50	392.50	66797.13		
	9:10	5	71.0	74.00	370.00	67167.13		
	9:15	5	67.0	69.00	345.00	67512.13		
	9:20	5	62.0	64.50	322.50	67834.63		
	9:25	5	60.0	61.00	305.00	68139.63		

Table C-1. (continued) Carbon adsorption breakthrough curve of acetic acid. Influent concentration (C_{in}) = 0.14 M, GAC = 400 g.

No.	Initial time	Time usage	Flow rate	Average flow rate	Volume of water	Cumulative volume of	Effluent conc. (M)	C_{out}/C_{in}
		(min.)	(ml/min.)	(ml/min.)	treated (ml)	water treated (ml)	C_{out}	
208	9:30	5	54.0	57.00	285.00	68424.63	0.13960	1.00014
	9:35	5	50.0	52.00	260.00	68684.63		
	9:40	5	46.0	48.00	240.00	68924.63		
	9:45	5	40.0	43.00	215.00	69139.63		
	9:50	5	36.0	38.00	190.00	69329.63		
	9:55	5	31.0	33.50	167.50	69497.13		
209	10:00	5	24.0	27.50	137.50	69634.63	0.13639	0.97714
	10:02	2	104.0		0.00	69634.63		
	10:05	5	88.0	96.00	480.00	70114.63		
	10:15	5	84.0	86.00	430.00	70544.63		
	10:20	5	81.0	82.50	412.50	70957.13		
	10:25	5	70.0	75.50	377.50	71334.63		
210	10:30	5	70.0	70.00	350.00	71684.63	0.13883	0.99462
	10:35	5	64.0	67.00	335.00	72019.63		
	10:40	5	64.0	64.00	320.00	72339.63		
	10:45	5	58.0	61.00	305.00	72644.63		
	10:50	5	54.0	56.00	280.00	72924.63		
	10:55	5	52.0	53.00	265.00	73189.63		
211	11:00	5	50.0	51.00	255.00	73444.63	0.13871	0.99376
	11:05	5	44.0	47.00	235.00	73679.63		
	11:10	5	41.0	42.50	212.50	73892.13		
	11:15	5	35.0	38.00	190.00	74082.13		
	11:20	5	32.0	33.50	167.50	74249.63		
	11:25	5	30.0	31.00	155.00	74404.63		
212	11:30	5	26.0	28.00	140.00	74544.63	0.13709	0.98216
	11:35	5	126.0		0.00	74544.63		
	11:40	5	117.0	121.50	607.50	75152.13		

Table C-1. (continued) Carbon adsorption breakthrough curve of acetic acid. Influent concentration (C_{in}) = 0.14 M, GAC = 400 g.

No.	Initial time	Time usage	Flow rate	Average flow rate	Volume of water	Cumulative volume of	Effluent conc. (M)	C_{out}/C_{in}
		(min.)	(ml/min.)	(ml/min.)	treated (ml)	water treated (ml)	C_{out}	
213	11:44	4	138.0	127.50	510.00	75662.13	0.14047	1.00637
	11:45	1	117.6	127.80	127.80	75789.93		
	11:49	4	117.6	117.60	470.40	76260.33		
	11:50	1	84.0	100.80	100.80	76361.13		
	11:55	5	76.0	80.00	400.00	76761.13		
	12:00	5	71.0	73.50	367.50	77128.63		
	12:05	5	66.0	68.50	342.50	77471.13		
	12:10	5	61.0	63.50	317.50	77788.63		
	12:15	5	54.0	57.50	287.50	78076.13		
	12:20	5	52.0	53.00	265.00	78341.13		
214	12:25	5	47.0	49.50	247.50	78588.63	0.13844	0.99183
	12:30	5	46.0	46.50	232.50	78821.13		
	12:35	5	26.0	36.00	180.00	79001.13		
	12:40	5	110.4		0.00	79001.13		
	12:45	5	100.0	105.20	526.00	79527.13		
	12:50	5	46.0	73.00	365.00	79892.13		
215	12:55	5	44.0	45.00	225.00	80117.13	0.13658	0.97850
	13:00	5	42.0	43.00	215.00	80332.13		
	13:05	5	40.0	41.00	205.00	80537.13		
	13:10	5	38.0	39.00	195.00	80732.13		
	13:15	5	38.0	38.00	190.00	80922.13		
	13:20	5	38.0	38.00	190.00	81112.13		
	13:25	5	64.0		0.00	81112.13		
	13:30	5			0.00	81112.13		
	13:35	5	48.0		0.00	81112.13		
	13:36	1	63.0	55.50	55.50	81167.63		
13:40	5	68.0	65.50	327.50	81495.13			

Table C-1. (continued) Carbon adsorption breakthrough curve of acetic acid. Influent concentration (C_{in}) = 0.14 M, GAC = 400 g.

No.	Initial time	Time usage (min.)	Flow rate (ml/min.)	Average flow rate (ml/min.)	Volume of water treated (ml)	Cumulative volume of water treated (ml)	Effluent conc. (M) C_{out}	C_{out}/C_{in}
216	13:45	5	62.0	65.00	325.00	81820.13	0.13733	0.98388
	13:50	5	59.0	60.50	302.50	82122.63		
	13:55	5	54.0	56.50	282.50	82405.13		
	14:00	5	50.0	52.00	260.00	82665.13		
	14:05	5	46.0	48.00	240.00	82905.13		
	14:10	5	40.0	43.00	215.00	83120.13		
	14:15	5	34.0	37.00	185.00	83305.13		
	14:17	2	79.0		0.00	83305.13		
217	14:20	3	79.0	79.00	237.00	83542.13	0.13775	0.98688
	14:25	5	73.0	76.00	380.00	83922.13		
	14:30	5	72.0	72.50	362.50	84284.63		
	14:35	5	67.0	69.50	347.50	84632.13		
	14:40	5	66.0	66.50	332.50	84964.63		
	14:45	5	62.0	64.00	320.00	85284.63		
	14:50	5	62.0	62.00	310.00	85594.63		
218	14:55	5	58.0	60.00	300.00	85894.63	0.13971	1.00093
	15:00	5	54.0	56.00	280.00	86174.63		
	15:05	5	52.0	53.00	265.00	86439.63		
	15:10	5	49.0	50.50	252.50	86692.13		
	15:15	5	46.0	47.50	237.50	86929.63		
	15:20	5	42.0	44.00	220.00	87149.63		
219	15:25	5	41.0	41.50	207.50	87357.13	0.13822	0.99025
	15:30	5	40.0	40.50	202.50	87559.63		
	15:34	4	124.5		0.00	87559.63		
	15:40	5	114.0	119.25	596.25	88155.88		
	15:45	5	105.0	109.50	547.50	88703.38		
	15:50	5	108.0	106.50	532.50	89235.88		

Table C-1. (continued) Carbon adsorption breakthrough curve of acetic acid. Influent concentration (C_{in}) = 0.14 M, GAC = 400 g.

No.	Initial time	Time usage	Flow rate	Average flow rate	Volume of water	Cumulative volume of	Effluent conc. (M)	C_{out}/C_{in}
		(min.)	(ml/min.)	(ml/min.)	treated (ml)	water treated (ml)	C_{out}	
220	15:55	5	93.0	100.50	502.50	89738.38	0.13709	0.98216
	16:00	5	99.0	96.00	480.00	90218.38		
	16:05	5	102.0	100.50	502.50	90720.88		
	16:10	5	78.0	90.00	450.00	91170.88		
	16:15	5	81.0	79.50	397.50	91568.38		
	16:20	5	69.0	75.00	375.00	91943.38		
	16:25	5	69.0	69.00	345.00	92288.38		
221	16:30	5	60.0	64.50	322.50	92610.88	0.13844	0.99183
	16:33	3	189.0		0.00	92610.88		
	16:34	1	114.0	151.50	151.50	92762.38		
	16:36	2	78.0	96.00	192.00	92954.38		
	16:40	4	72.0	75.00	300.00	93254.38		
	16:45	5	69.0	70.50	352.50	93606.88		
	16:50	5	66.0	67.50	337.50	93944.38		
222	16:55	5	60.0	63.00	315.00	94259.38	0.13853	0.99247
	17:00	5	60.0	60.00	300.00	94559.38		
	17:05	5	60.0	60.00	300.00	94859.38		
	17:10	5	60.0	60.00	300.00	95159.38		
	17:15	5	54.0	57.00	285.00	95444.38		
	17:20	5	54.0	54.00	270.00	95714.38		
	17:25	5	54.0	54.00	270.00	95984.38		
223	17:30	5	51.0	52.50	262.50	96246.88	0.13806	0.98911
	17:35	5	51.0	51.00	255.00	96501.88		
	17:40	5	51.0	51.00	255.00	96756.88		
	17:45	5	42.0	46.50	232.50	96989.38		
224	17:50	5	42.0	42.00	210.00	97199.38	0.13764	0.98610
	6:33		72.0					

Table C-1. (continued) Carbon adsorption breakthrough curve of acetic acid. Influent concentration (C_{in}) = 0.14 M, GAC = 400 g.

No.	Initial time	Time usage	Flow rate	Average flow rate	Volume of water	Cumulative volume of	Effluent conc. (M)	C_{out}/C_{in}
		(min.)	(ml/min.)	(ml/min.)	treated (ml)	water treated (ml)	C_{out}	
225	6:37	4	66.0	69.00	276.00	97475.38	0.13956	0.99985
	6:40	3	66.0	66.00	198.00	97673.38		
	6:42	2	129.0	66.00	132.00	97805.38		
	6:45	3	126.0	127.50	382.50	98187.88		
	6:50	5	84.0	126.00	630.00	98817.88		
	6:55	5	83.0	83.50	417.50	99235.38		
	7:00	5	79.0	81.00	405.00	99640.38		
	7:05	5	75.0	77.00	385.00	100025.38		
	7:10	5	72.0	73.50	367.50	100392.88		
	7:15	5	68.0	70.00	350.00	100742.88		
226	7:20	5	64.0	66.00	330.00	101072.88	0.14096	1.00988
	7:25	5	60.0	62.00	310.00	101382.88		
	7:30	5	55.0	57.50	287.50	101670.38		
	7:35	5	53.0	54.00	270.00	101940.38		
	7:40	5	50.0	51.50	257.50	102197.88		
	7:45	5	48.0	49.00	245.00	102442.88		
	7:50	5	45.0	46.50	232.50	102675.38		
	7:53	3	150.5	150.50	451.50	103126.88		
	7:54	1	60.0	60.00	60.00	103186.88		
	7:55	1	49.0	49.00	49.00	103235.88		
227	8:00	5	50.0	49.50	247.50	103483.38	0.13967	1.00064
	8:05	5	46.0	48.00	240.00	103723.38		
	8:06	1	66.0	66.00	66.00	103789.38		
	8:10	4	47.0	66.00	264.00	104053.38		
	8:15	5	68.0	66.00	330.00	104383.38		
	8:20	5	66.0	66.00	330.00	104713.38		
	8:25	5	64.0	66.00	330.00	105043.38		

Table C-1. (continued) Carbon adsorption breakthrough curve of acetic acid. Influent concentration (C_{in}) = 0.14 M, GAC = 400 g.

No.	Initial time	Time usage	Flow rate	Average flow rate	Volume of water	Cumulative volume of	Effluent conc. (M)	C_{out}/C_{in}
		(min.)	(ml/min.)	(ml/min.)	treated (ml)	water treated (ml)	C_{out}	
228	8:30	5	60.0	66.00	330.00	105373.38	0.14105	1.01053
	8:35	5	59.0	66.00	330.00	105703.38		
	8:40	5	56.0	66.00	330.00	106033.38		
	8:45	5	54.0	66.00	330.00	106363.38		
	8:50	5	51.0	66.00	330.00	106693.38		
	8:55	5	50.0	66.00	330.00	107023.38		
229	9:00	5	46.0	66.00	330.00	107353.38	0.14069	1.00795
	9:05	5	44.0	66.00	330.00	107683.38		
	9:10	5	42.0	66.00	330.00	108013.38		
	9:15	5	40.0	66.00	330.00	108343.38		
	9:20	5	40.0	66.00	330.00	108673.38		
	9:22	2	90.0	90.00	180.00	108853.38		
230	9:25	3	90.0	90.00	270.00	109123.38	0.14070	1.00802
	9:30	5	82.0	86.00	430.00	109553.38		
	9:35	5	82.0	82.00	410.00	109963.38		
	9:40	5	84.0	83.00	415.00	110378.38		
	9:45	5	78.0	81.00	405.00	110783.38		
	9:50	5	71.0	74.50	372.50	111155.88		
231	9:55	5	66.0	68.50	342.50	111498.38	0.13642	0.97736
	10:00	5	64.0	65.00	325.00	111823.38		
	10:05	5	61.0	62.50	312.50	112135.88		
	10:10	5	57.0	59.00	295.00	112430.88		
	10:15	5	54.0	55.50	277.50	112708.38		
	10:20	5	54.0	54.00	270.00	112978.38		
232	10:25	5	51.0	52.50	262.50	113240.88	0.13485	0.96611
	10:30	5	48.0	49.50	247.50	113488.38		
	10:35	5	48.0	48.00	240.00	113728.38		

Table C-1. (continued) Carbon adsorption breakthrough curve of acetic acid. Influent concentration (C_{in}) = 0.14 M, GAC = 400 g.

No.	Initial time	Time usage (min.)	Flow rate (ml/min.)	Average flow rate (ml/min.)	Volume of water treated (ml)	Cumulative volume of water treated (ml)	Effluent conc. (M) C_{out}	C_{out}/C_{in}
233	10:40	5	44.0	46.00	230.00	113958.38	0.13417	0.96124
	10:41	1	96.0	96.00	96.00	114054.38		
	10:45	4	76.0	74.00	296.00	114350.38		
	10:50	5	72.0	69.50	347.50	114697.88		
	10:55	5	67.0	67.50	337.50	115035.38		
	11:00	5	68.0	66.50	332.50	115367.88		
	11:05	5	65.0	64.50	322.50	115690.38		
	11:10	5	64.0	62.00	310.00	116000.38		
	11:15	5	60.0	59.50	297.50	116297.88		
	11:20	5	59.0	58.00	290.00	116587.88		
234	11:25	5	57.0	56.00	280.00	116867.88	0.13583	0.97313
	11:30	5	55.0	77.00	385.00	117252.88		
	11:35	5	99.0	99.00	495.00	117747.88		
	11:40	5	86.0	92.50	462.50	118210.38		
	11:45	5	80.0	83.00	415.00	118625.38		
	11:50	5	75.0	77.50	387.50	119012.88		
	11:55	5	66.0	70.50	352.50	119365.38		
235	12:00	5	60.0	63.00	315.00	119680.38	0.13500	0.96718

APPENDIX D

Data of Breakthrough Curve for Ethyl acetate

Table D-1. Carbon adsorption breakthrough curve of ethyl acetate. Influent concentration (C_{in}) = 0.10 M, GAC = 400 g.

No.	Initial time	Time usage (min.)	Flow Rate (ml/min.)	Average flow rate (ml/min.)	Volume of water treated (ml)	Cumulative volume of water treated (ml)	Effluent Conc. (M) C_{out}	C_{out}/C_{in}
	13:25		17.0					
	13:28	3	22.0	19.50	58.50	58.50		
1	13:35	7	21.0	21.50	150.50	209.00	0.00000	0.00000
2	13:40	5	20.0	20.50	102.50	311.50	0.00000	0.00000
3	13:50	10	18.0	19.00	190.00	501.50	0.00000	0.00000
4	14:00	10	16.0	17.00	170.00	671.50	0.00000	0.00000
5	14:10	10	16.0	16.00	160.00	831.50	0.00000	0.00000
6	14:20	10	15.5	15.75	157.50	989.00	0.00000	0.00000
7	14:30	10	15.0	15.25	152.50	1141.50	0.00000	0.00000
8	14:40	10	14.0	14.50	145.00	1286.50	0.00000	0.00000
9	14:50	10	14.0	14.00	140.00	1426.50	0.00000	0.00000
10	15:00	10	14.0	14.00	140.00	1566.50	0.00000	0.00000
11	15:10	10	12.5	13.25	132.50	1699.00	0.00000	0.00000
12	15:20	10	12.0	12.25	122.50	1821.50	0.00000	0.00000
13	15:30	10	12.0	12.00	120.00	1941.50	0.00000	0.00000
14	15:40	10	11.0	11.50	115.00	2056.50	0.00000	0.00000
15	15:50	10	10.5	10.75	107.50	2164.00	0.00000	0.00000
16	16:00	10	10.0	10.25	102.50	2266.50	0.00000	0.00000
	17:16	6	12.0	11.00	66.00	2332.50		
17	17:20	4	12.0	12.00	48.00	2380.50	0.00000	0.00000
18	17:30	10	11.0	11.50	115.00	2495.50	0.00000	0.00000
19	17:40	10	10.0	10.50	105.00	2600.50	0.00000	0.00000
20	17:47	7	9.0	9.50	66.50	2667.00	0.00000	0.00000
	11:12	5	22.5		0.00			0.00000
21	11:20	8	19.0	20.75	166.00	2833.00	0.00000	
22	11:30	10	17.0	18.00	180.00	3013.00	0.00000	0.00000
23	11:40	10	15.5	16.25	162.50	3175.50	0.00000	0.00000

Table D-1. (continued) Carbon adsorption breakthrough curve of ethyl acetate. Influent concentration (C_{in}) = 0.10 M, GAC = 400 g.

No.	Initial time	Time usage (min.)	Flow Rate (ml/min.)	Average flow rate (ml/min.)	Volume of water treated (ml)	Cumulative volume of water treated (ml)	Effluent Conc (M) C_{out}	C_{out}/C_{in}
24	11:50	10	13.0	14.25	142.50	3318.00	0.00000	0.00000
25	12:00	10	11.0	12.00	120.00	3438.00	0.00000	0.00000
26	12:10	10	10.0	10.50	105.00	3543.00	0.00000	0.00000
27	12:20	10	9.5	9.75	97.50	3640.50	0.00000	0.00000
	12:23	3	18.0	9.50	28.50	3669.00		
28	12:30	7	16.0	17.00	119.00	3788.00	0.00000	0.00000
29	12:40	10	15.5	15.75	157.50	3945.50	0.00000	0.00000
30	12:50	10	15.0	15.25	152.50	4098.00	0.00000	0.00000
31	13:00	10	14.0	14.50	145.00	4243.00	0.00000	0.00000
32	13:10	10	14.0	14.00	140.00	4383.00	0.00000	0.00000
	14:40	10	39.5		0.00			
	14:50	10	35.0	37.25	372.50	4755.50		
33	15:00	10	32.5	33.75	337.50	5093.00	0.00000	0.00000
	15:10	10	30.0	31.25	312.50	5405.50		
34	15:20	10	28.0	29.00	290.00	5695.50	0.00321	0.03147
	15:30	10	27.0	27.50	275.00	5970.50		
35	15:40	10	26.0	26.50	265.00	6235.50	0.00098	0.00963
	15:50	10	24.0	25.00	250.00	6485.50		
36	16:00	10	23.0	23.50	235.00	6720.50	0.00220	0.02164
	16:10	10	21.0	22.00	220.00	6940.50		
	16:20	10	20.0	20.50	205.00	7145.50		
37	16:30	10	19.5	19.75	197.50	7343.00	0.00058	0.00574
	16:40	10	18.0	18.75	187.50	7530.50		
	16:50	10	16.0	17.00	170.00	7700.50		
38	17:00	10	15.0	15.50	155.00	7855.50	0.00140	0.01374
	17:10	10	13.5	14.25	142.50	7998.00		
	17:20	10	12.0	12.75	127.50	8125.50		

Table D-1. (continued) Carbon adsorption breakthrough curve of ethyl acetate. Influent concentration (C_{in}) = 0.10 M, GAC = 400 g

No.	Initial time	Time usage	Flow Rate	Average flow rate	Volume of water	Cumulative volume of	Effluent Conc. (M)	C_{out}/C_{in}
		(min.)	(ml/min.)	(ml/min.)	treated (ml)	water treated (ml)	C_{out}	
39	17:30	10	10.0	11.00	110.00	8235.50	0.00283	0.02773
	17:40	10	9.0	9.50	95.00	8330.50		
	17:41	1	13.0	9.00	9.00	8339.50		
	17:50	9	12.0	12.50	112.50	8452.00		
40	18:00	10	11.0	11.50	115.00	8567.00	0.00598	0.05863
	11:10	10	21.5	0.00	0.00	0.00		
	11:20	10	19.0	20.25	202.50	8769.50		
	11:30	10	18.0	18.50	185.00	8954.50		
41	11:40	10	18.0	18.00	180.00	9134.50	0.00382	0.03747
	11:50	10	14.0	16.00	160.00	9294.50		
42	12:00	10	13.5	13.75	137.50	9432.00	0.00694	0.06806
	12:10	10	12.0	12.75	127.50	9559.50		
	12:20	10	11.5	11.75	117.50	9677.00		
43	12:30	10	11.0	11.25	112.50	9789.50	0.01136	0.11134
	12:40	10	11.0	11.00	110.00	9899.50		
	12:50	10	10.5	10.75	107.50	10007.00		
44	13:00	10	10.5	10.50	105.00	10112.00	0.01466	0.14371
	13:10	10	10.0	10.25	102.50	10214.50		
	13:20	10	10.0	10.00	100.00	10314.50		
45	13:30	10	9.5	9.75	97.50	10412.00	0.01696	0.16621
	13:40	10	9.0	9.25	92.50	10504.50		
	13:50	10	8.5	8.75	87.50	10592.00		
46	14:00	10	8.0	8.25	82.50	10674.50	0.02116	0.20739
	14:03	3	9.0	8.50	25.50	10700.00		
	14:10	7	9.0	9.00	63.00	10763.00		
	14:20	10	9.0	9.00	90.00	10853.00		
47	14:30	10	9.0	9.00	90.00	10943.00	0.02473	0.24233

Table D-1. (continued) Carbon adsorption breakthrough curve of ethyl acetate. Influent concentration (C_{in}) = 0.10 M, GAC = 400 g.

No.	Initial time	Time usage (min.)	Flow Rate (ml/min.)	Average flow rate (ml/min.)	Volume of water treated (ml)	Cumulative volume of water treated (ml)	Effluent Conc. (M) C_{out}	C_{out}/C_{in}
48	14:45	15	8.5	8.75	131.25	11074.25	0.02815	0.27587
	14:50	5	8.0	8.25	41.25	11115.50		
	15:00	10	8.0	8.00	80.00	11195.50		
	15:10	10	31.0	8.00	80.00	11275.50		
49	15:20	10	29.0	30.00	300.00	11575.50	0.03428	0.33598
	15:30	10	26.5	27.75	277.50	11853.00		
	15:40	10	26.0	26.25	262.50	12115.50		
50	15:50	10	24.0	25.00	250.00	12365.50	0.03988	0.39083
	16:00	10	24.0	24.00	240.00	12605.50		
	16:10	10	22.5	23.25	232.50	12838.00		
50	16:20	10	22.5	22.50	225.00	13063.00	0.04852	0.47545
	16:30	10	22.0	22.25	222.50	13285.50		
	16:40	10	20.5	21.25	212.50	13498.00		
51	16:50	10	20.0	20.25	202.50	13700.50	0.04514	0.44233
	17:00	10	19.5	19.75	197.50	13898.00		
	17:10	10	38.0	19.50	195.00	14093.00		
52	17:20	10	35.0	36.50	365.00	14458.00	0.05265	0.51594
	17:30	10	33.0	34.00	340.00	14798.00		
	17:40	10	29.0	31.00	310.00	15108.00		
53	17:50	10	27.0	28.00	280.00	15388.00	0.05313	0.52066
	18:00	10	24.0	25.50	255.00	15643.00		
	8:05	5	17.5		0.00			
54	8:20	15	14.0	15.75	236.25	15879.25	0.05131	0.50286
	8:30	10	12.5	13.25	132.50	16011.75		
	8:40	10	11.5	12.00	120.00	16131.75		
	8:50	10	10.0	10.75	107.50	16239.25		
55	9:00	10	8.5	9.25	92.50	16331.75	0.05860	0.57431

Table D-1. (continued) Carbon adsorption breakthrough curve of ethyl acetate. Influent concentration (C_{in}) = 0.10 M, GAC = 400 g.

No.	Initial time	Time usage (min.)	Flow Rate (ml/min.)	Average flow rate (ml/min.)	Volume of water treated (ml)	Cumulative volume of water treated (ml)	Effluent Conc. (M) C_{out}	C_{out}/C_{in}
56	9:15	15	25.5	8.50	127.50	16459.25	0.06324	0.61971
	9:20	5	24.5	25.00	125.00	16584.25		
	9:25	5	23.0	23.75	118.75	16703.00		
	9:30	5	23.0	23.00	115.00	16818.00		
	9:35	5	21.5	22.25	111.25	16929.25		
	9:40	5	20.0	20.75	103.75	17033.00		
	9:50	10	17.0	18.50	185.00	17218.00		
	10:00	10	16.0	16.50	165.00	17383.00		
	10:10	10	15.5	15.75	157.50	17540.50		
	10:20	10	15.0	15.25	152.50	17693.00		
57	10:30	10	14.0	14.50	145.00	17838.00	0.06598	0.64661
	10:40	10	13.0	13.50	135.00	17973.00		
	10:50	10	12.5	12.75	127.50	18100.50		
	11:00	10	12.0	12.25	122.50	18223.00		
	11:10	10	12.0	12.00	120.00	18343.00		
	11:20	10	10.0	11.00	110.00	18453.00		
	11:30	10	9.0	9.50	95.00	18548.00		
	11:31	1	32.0	9.00	9.00	18557.00		
	11:35	4	31.5	31.75	127.00	18684.00		
	11:45	10	30.0	30.75	307.50	18991.50		
58	11:50	5	29.0	29.50	147.50	19139.00	0.06570	0.64380
	11:55	5	28.0	28.50	142.50	19281.50		
	12:00	5	27.0	27.50	137.50	19419.00		
	12:10	10	25.0	26.00	260.00	19679.00		
	12:15	5	24.0	24.50	122.50	19801.50		
	12:20	5	23.5	23.75	118.75	19920.25		
	12:25	5	23.0	23.25	116.25	20036.50		

Table D-1. (continued) Carbon adsorption breakthrough curve of ethyl acetate. Influent concentration (C_{in}) = 0.10M, GAC = 400 g.

No.	Initial time	Time usage (min.)	Flow Rate (ml/min.)	Average flow rate (ml/min.)	Volume of water treated (ml)	Cumulative volume of water treated (ml)	Effluent Conc. (M) C_{out}	C_{out}/C_{in}
	12:30	5	22.0	22.50	112.50	20149.00		
	12:35	5	21.0	21.50	107.50	20256.50		
	12:40	5	20.0	20.50	102.50	20359.00		
	12:45	5	18.5	19.25	96.25	20455.25		
	12:50	5	18.0	18.25	91.25	20546.50		
	12:55	5	17.0	17.50	87.50	20634.00		
59	13:00	5	16.0	16.50	82.50	20716.50	0.04531	0.44405
	7:15	0	48.0	0.00				
60	15:30	15	45.5	46.75	701.25	21417.75	0.06216	0.60913
61	15:45	15	50.0	45.50	682.50	22100.25	0.06329	0.62019
62	16:00	15	49.0	49.50	742.50	22842.75	0.06473	0.63433
63	16:15	15	47.5	48.25	723.75	23566.50	0.06455	0.63259
64	16:30	15	41.0	44.25	663.75	24230.25	0.06133	0.60102
65	16:45	15	43.2	41.00	615.00	24845.25	0.06175	0.60512
66	17:00	15	40.5	41.83	627.38	25472.63	0.05769	0.56534
67	17:15	15	39.0	39.75	596.25	26068.88	0.06163	0.60392
	7:00		45.5	0.00				
68	7:10	10	41.0	43.25	432.50	26501.38	0.05649	0.55359
69	7:20	10	40.0	40.50	405.00	26906.38	0.05162	0.50587
70	7:30	10	37.0	38.50	385.00	27291.38	0.05248	0.51427
71	7:40	10	37.0	37.00	370.00	27661.38	0.06188	0.60639
72	7:50	10	36.0	36.50	365.00	28026.38	0.05305	0.51984
73	8:00	10	35.0	35.50	355.00	28381.38	0.06686	0.65524
74	8:10	10	31.0	33.00	330.00	28711.38	0.05800	0.56836
75	8:20	10	31.0	31.00	310.00	29021.38	0.05232	0.51274
76	8:30	10	29.5	30.25	302.50	29323.88	0.06542	0.64106
77	8:40	10	29.5	29.50	295.00	29618.88	0.06289	0.61633

Table D-1. (continued) Carbon adsorption breakthrough curve of ethyl acetate. Influent concentration (C_{in}) = 0.10 M, GAC = 400 g.

No.	Initial time	Time usage (min.)	Flow Rate (ml/min.)	Average flow rate (ml/min.)	Volume of water treated (ml)	Cumulative volume of water treated (ml)	Effluent Conc. (M) C_{out}	C_{out}/C_{in}
78	8:50	10	28.0	28.75	287.50	29906.38	0.05090	0.49878
79	9:00	10	26.0	27.00	270.00	30176.38	0.06127	0.60043
80	9:20	10	26.0	26.00	260.00	30436.38	0.06270	0.61447
81	9:30	10	25.0	25.50	255.00	30691.38	0.05790	0.56744
82	9:40	10	24.5	24.75	247.50	30938.88	0.06390	0.62624
83	9:50	10	23.0	23.75	237.50	31176.38	0.06021	0.59001
84	10:00	10	23.0	23.00	230.00	31406.38	0.05802	0.56857
85	10:10	10	22.5	22.75	227.50	31633.88	0.05833	0.57159
86	10:20	10	21.5	22.00	220.00	31853.88	0.05147	0.50437
87	10:30	10	21.0	21.25	212.50			
88	10:40	10	19.0	20.00	200.00	32053.88	0.06184	0.60601
89	10:50	10	18.5	18.75	187.50	32241.38	0.05171	0.50680
90	11:00	10	18.0	18.25	182.50	32236.38	0.04873	0.47751
91	11:10	10	17.0	17.50	175.00	32416.38	0.05340	0.52331
92	11:20	10	16.0	16.50	165.00	32401.38	0.04155	0.40721
93	11:30	10	15.5	15.75	157.50	32573.88	0.04693	0.45996
94	11:40	10	15.0	15.25	152.50	32553.88	0.04090	0.40079
95	11:50	10	14.0	14.50	145.00	32718.88	0.05884	0.57661
96	12:00	10	14.0	14.00	140.00	32693.88	0.05005	0.49052
97	12:10	10	13.0	13.50	135.00	32853.88	0.06090	0.59682
	12:40	10	10.5	11.75				
98	12:50	10	10.5	10.50	105.00	32958.88	0.05169	0.50656
	12:55	5	27.0	10.50				
99	13:00	5	24.5	25.75	128.75	33087.63	0.02240	0.21950
	13:05	5	38.0	24.50				
100	13:10	5	30.5	34.25	171.25	33258.88	0.05867	0.57498
101	13:20	10	30.5	30.50	305.00	33563.88	0.05654	0.55405

Table D-1. (continued) Carbon adsorption breakthrough curve of ethyl acetate. Influent concentration (C_{in}) = 0.10M, GAC = 400 g.

No.	Initial time	Time usage (min.)	Flow Rate (ml/min.)	Average flow rate (ml/min.)	Volume of water treated (ml)	Cumulative volume of water treated (ml)	Effluent Conc. (M) C_{out}	C_{out}/C_{in}
102	13:30	10	30.5	30.50	305.00	33868.88	0.05069	0.49671
103	13:40	10	29.5	30.00	300.00	34168.88	0.05540	0.54287
104	13:55	10	29.0	29.25	292.50	34461.38	0.04923	0.48248
105	14:00	10	29.0	29.00	290.00	34751.38	0.05215	0.51104
106	14:10	10	26.3	27.65	276.50	35027.88	0.05311	0.52045
107	14:20	10	26.3	26.30	263.00	35290.88	0.05164	0.50608
108	14:30	10	25.7	26.00	260.00	35550.88	0.05467	0.53578
109	14:40	10	25.0	25.35	253.50	35804.38	0.05271	0.51660
110	14:50	10	24.0	24.50	245.00	36049.38	0.06406	0.62773
111	15:00	10	23.5	23.75	237.50	36286.88	0.05382	0.52745
112	15:10	10	23.0	23.25	232.50	36519.38	0.05842	0.57248
113	15:20	10	22.0	22.50	225.00	36744.38	0.06390	0.62624
114	15:30	10	22.0	22.00	220.00	36964.38	0.05579	0.54671
115	15:40	10	22.0	22.00	220.00	37184.38	0.06604	0.64716
116	15:50	10	21.0	21.50	215.00	37399.38	0.04940	0.48410
117	16:00	10	20.2	20.60	206.00	37605.38	0.05831	0.57139
118	16:10	10	33.0	20.20	202.00	37807.38	0.05570	0.54585
119	16:20	10	33.0	33.00	330.00	38137.38	0.05239	0.51346
120	16:30	10	31.5	32.25	322.50	38459.88	0.05250	0.51454
121	16:40	10	31.0	31.25	312.50	38772.38	0.05173	0.50698
122	16:50	10	29.5	30.25	302.50	39074.88	0.04725	0.46302
123	17:00	10	28.5	29.00	290.00	39364.88	0.05106	0.50039
	18:34		57.5	28.50				
124	18:40	6	54.0	55.75	334.50	39699.38	0.043854	0.42973
	18:44	6	25.0	54.00				
125	18:50	6	23.5	24.25	145.50	39844.88	0.05652	0.55385
126	19:00	10	23.0	23.25	232.50	40077.38	0.04745	0.46498

Table D-1. (continued) Carbon adsorption breakthrough curve of ethyl acetate. Influent concentration (C_{in}) = 0.10 M, GAC = 400 g.

No.	Initial time	Time usage (min.)	Flow Rate (ml/min.)	Average flow rate (ml/min.)	Volume of water treated (ml)	Cumulative volume of water treated (ml)	Effluent Conc. (M) C_{out}	C_{out}/C_{in}
127	19:10	10	21.0	22.00	220.00	40297.38	0.05479	0.53698
128	19:20	10	20.0	20.50	205.00	40502.38	0.04784	0.46880
129	19:30	10	19.0	19.50	195.00	40697.38	0.06144	0.60207
130	19:40	10	17.5	18.25	182.50	40879.88	0.04841	0.47439
131	19:50	10	15.0	16.25	162.50	41042.38	0.04729	0.46343
	19:55	6	21.0	15.00				
132	20:00	5	19.5	20.25	101.25	41143.63	0.05104	0.50023
133	20:10	10	18.0	18.75	187.50	41331.13	0.04677	0.45838
134	20:20	10	17.0	17.50	175.00	41506.13	0.04685	0.45916
	6:40		32.5	0.00				
135	6:50	10	28.5	30.50	305.00	41811.13	0.04938	0.48388
136	7:00	10	23.0	25.75	257.50	42068.63	0.04062	0.39812
137	7:10	10	20.0	21.50	215.00	42026.13	0.05404	0.52954
138	7:20	10	20.0	20.00	200.00	42268.63	0.04825	0.47288
139	7:30	10	20.0	20.00	200.00	42226.13	0.05013	0.49124
140	7:40	10	18.5	19.25	192.50	42461.13	0.06114	0.59913
141	7:50	10	18.5	18.50	185.00	42411.13	0.05171	0.50679
142	8:00	10	18.5	18.50	185.00	42646.13	0.05628	0.55153
143	8:10	10	18.5	18.50	185.00	42596.13	0.05283	0.51776
144	8:20	10	18.0	18.25	182.50	42828.63	0.03959	0.38801
145	8:30	10	17.0	17.50	175.00	42771.13	0.04539	0.44486
146	8:40	10	17.0	17.00	170.00	42998.63	0.03915	0.38368
147	8:50	10	16.0	16.50	165.00	42936.13	0.04694	0.46000
148	9:00	10	15.5	15.75	157.50	43156.13	0.06122	0.59995
149	9:10	10	15.0	15.25	152.50	43088.63	0.05742	0.56270
	10:45		29.0	0.00				
150	10:50	5	20.0	24.50	122.50	43211.13	0.05780	0.56644

Table D-1. (continued) Carbon adsorption breakthrough curve of ethyl acetate. Influent concentration (C_{in}) = 0.10 M, GAC = 400 g.

No.	Initial time	Time usage (min.)	Flow Rate (ml/min.)	Average flow rate (ml/min.)	Volume of water treated (ml)	Cumulative volume of water treated (ml)	Effluent Conc. (M) C_{out}	C_{out}/C_{in}
151	11:00	10	19.0	19.50	195.00	43406.13	0.04619	0.45268
152	11:10	10	18.0	18.50	185.00	43591.13	0.05475	0.53655
153	11:20	10	17.5	17.75	177.50	43768.63	0.05300	0.51944
154	11:30	10	16.5	17.00	170.00	43938.63	0.05291	0.51851
155	11:40	10	15.0	15.75	157.50	44096.13	0.04516	0.44261
156	11:50	10	14.5	14.75	147.50	44243.63	0.04581	0.44896
157	12:00	10	13.0	13.75	137.50	44381.13	0.05432	0.53236
	12:02	2	18.5	13.00				
158	12:10	8	17.0	17.75	142.00	44523.13	0.04587	0.44957
	12:12	2	26.0	17.00				
159	12:20	8	15.0	20.50	164.00	44687.13	0.04486	0.43964
	12:25	5	42.0	15.00				
160	12:30	5	39.0	40.50	202.50	44889.63	0.04009	0.39292
161	12:40	10	31.0	35.00	350.00	45239.63	0.05530	0.54191
162	12:50	10	27.5	29.25	292.50	45532.13	0.06093	0.59709
	7:17		35.5	0.00				
163	7:30	13	32.0	33.75	438.75	45970.88	0.06249	0.61234
164	7:40	10	29.0	30.50	305.00	46275.88	0.06272	0.61465
165	7:50	10	27.0	28.00	280.00	46250.88	0.06076	0.59547
166	8:00	10	25.0	26.00	260.00	46535.88	0.05612	0.54997
167	8:10	10	24.5	24.75	247.50	46498.38	0.05488	0.53778
168	8:20	10	22.5	23.50	235.00	46770.88	0.05536	0.54250
169	8:30	10	22.5	22.50	225.00	46723.38	0.06243	0.61176
170	8:40	10	20.5	21.50	215.00	46985.88	0.05572	0.54603
171	8:50	10	18.0	19.25	192.50	46915.88	0.05465	0.53557
172	9:00	10	17.5	17.75	177.50	47163.38	0.05412	0.53041
173	9:10	10	15.0	16.25	162.50	47078.38	0.05412	0.53040

Table D-1. (continued) Carbon adsorption breakthrough curve of ethyl acetate. Influent concentration (C_{in}) = 0.10 M, GAC = 400 g.

No.	Initial time	Time usage (min.)	Flow Rate (ml/min.)	Average flow rate (ml/min.)	Volume of water treated (ml)	Cumulative volume of water treated (ml)	Effluent Conc. (M) C_{out}	C_{out}/C_{in}
174	9:20	10	15.0	15.00	150.00	47313.38	0.05314	0.52078
175	9:30	10	14.0	14.50	145.00	47223.38	0.05448	0.53394
176	9:40	10	11.0	12.50	125.00	47438.38	0.05985	0.58656
177	9:50	10	10.0	10.50	105.00	47328.38	0.04882	0.47842
	9:54	6	25.0	10.00				
178	10:00	6	17.5	21.25	127.50	47455.88	0.04295	0.42094
179	10:10	10	13.5	15.50	155.00	47610.88	0.04956	0.48566
	10:15	5	25.0	13.50				
180	10:20	5	20.5	22.75	113.75	47724.63	0.05304	0.51980
181	10:30	10	19.0	19.75	197.50	47922.13	0.05350	0.52432
182	10:40	10	19.0	19.00	190.00	48112.13	0.04946	0.48466
183	10:50	10	18.0	18.50	185.00	48297.13	0.05261	0.51554
184	11:00	10	17.0	17.50	175.00	48472.13	0.05072	0.49701
185	11:10	10	17.0	17.00	170.00	48642.13	0.04818	0.47221
186	11:20	10	17.0	17.00	170.00	48812.13	0.03761	0.36862
187	11:30	10	16.0	16.50	165.00	48977.13	0.04585	0.44932
188	11:40	10	16.0	16.00	160.00	49137.13	0.05210	0.51056
189	11:50	10	15.0	15.50	155.00	49292.13	0.04943	0.48438
190	12:00	10	13.5	14.25	142.50	49434.63	0.04027	0.39466
191	12:10	10	14.5	13.50	135.00	49569.63	0.04931	0.48323
192	12:20	10	13.5	14.00	140.00	49709.63	0.04946	0.48472
193	12:30	10	13.0	13.25	132.50	49842.13	0.04088	0.40066
194	12:40	10	13.0	13.00	130.00	49972.13	0.04300	0.42144
195	12:50	10	12.5	12.75	127.50	50099.63	0.04568	0.44764
	13:17		51.5			50099.63		
	13:20	3	48.5	50.00	150.00	50249.63		
	13:25	5	48.0	48.25	241.25	50490.88		

Table D-1. (continued) Carbon adsorption breakthrough curve of ethyl acetate. Influent concentration (C_{in}) = 0.10 M, GAC = 400 g.

No.	Initial time	Time usage (min.)	Flow Rate (ml/min.)	Average flow rate (ml/min.)	Volume of water treated (ml)	Cumulative volume of water treated (ml)	Effluent Conc. (M) C_{out}	C_{out}/C_{in}
195	13:30	5	48.0	48.00	240.00	50730.88	0.05129	0.50259
	13:35	5	45.0	46.50	232.50	50963.38		
	13:40	5	43.5	44.25	221.25	51184.63		
	13:45	5	41.5	42.50	212.50	51397.13		
	13:50	5	40.0	40.75	203.75	51600.88		
	13:55	5	38.0	39.00	195.00	51795.88		
196	14:00	5	38.0	38.00	190.00	51985.88	0.05965	0.58455
	14:05	5	36.0	37.00	185.00	52170.88		
	14:10	5	35.0	35.50	177.50	52348.38		
	14:15	5	33.0	34.00	170.00	52518.38		
	14:20	5	33.0	33.00	165.00	52683.38		
	14:25	5	30.5	31.75	158.75	52842.13		
197	14:30	5	30.0	30.25	151.25	52993.38	0.05555	0.54439
	14:35	5	29.0	29.50	147.50	53140.88		
	14:40	5	28.0	28.50	142.50	53283.38		
	14:45	5	27.0	27.50	137.50	53420.88		
	14:46	5	41.0			53420.88		
	14:50	5	40.0	40.50	202.50	53623.38		
198	14:55	5	38.0	39.00	195.00	53818.38	0.06039	0.59176
	15:00	5	37.0	37.50	187.50	54005.88		
	15:05	5	33.5	35.25	176.25	54182.13		
	15:10	5	31.0	32.25	161.25	54343.38		
	15:15	5	28.5	29.75	148.75	54492.13		
	15:20	5	27.5	28.00	140.00	54632.13		
199	15:25	5	23.0	25.25	126.25	54758.38	0.05903	0.57846
	15:30	5	21.0	22.00	110.00	54868.38		
	15:34	5	46.0		0.00	54868.38		

Table D-1. (continued) Carbon adsorption breakthrough curve of ethyl acetate. Influent concentration (C_{in}) = 0.10 M, GAC = 400 g.

No.	Initial time	Time usage (min.)	Flow Rate (ml/min.)	Average flow rate (ml/min.)	Volume of water treated (ml)	Cumulative volume of water treated (ml)	Effluent Conc. (M) C_{out}	C_{out}/C_{in}			
200	15:40	5	44.0	45.00	225.00	55093.38	0.06320	0.61937			
	15:45	5	41.0	42.50	212.50	55305.88					
	15:50	5	41.0	41.00	205.00	55510.88					
	15:55	5	39.0	40.00	200.00	55710.88					
	16:00	5	37.5	38.25	191.25	55902.13					
	16:05	5	37.5	37.50	187.50	56089.63					
	16:10	5	37.0	37.25	186.25	56275.88					
	16:15	5	36.0	36.50	182.50	56458.38					
	16:20	5	35.0	35.50	177.50	56635.88					
	16:25	5	33.0	34.00	170.00	56805.88					
201	16:30	5	32.0	32.50	162.50	56968.38	0.06218	0.60932			
	16:35	5	31.0	31.50	157.50	57125.88					
	16:40	5	31.0	31.00	155.00	57280.88					
	16:45	5	30.0	30.50	152.50	57433.38					
	16:50	5	28.0	29.00	145.00	57578.38					
	16:55	5	28.0	28.00	140.00	57718.38					
	17:00	5	27.5	27.75	138.75	57857.13					
	17:02	2	42.0		0.00	57857.13					
	17:05	5	40.5	41.25	206.25	58063.38					
	17:10	5	38.0	39.25	196.25	58259.63					
202	17:15	5	37.0	37.50	187.50	58447.13	0.05893	0.57746			
	17:20	5	35.0	36.00	180.00	58627.13					
	17:25	5	33.5	34.25	171.25	58798.38					
	17:30	5	31.0	32.25	161.25	58959.63					
	7:03	5	31.0	31.00	155.00	59114.63					
	7:05	5	84.0		0.00	59114.63					
	7:10	5	78.0	81.00	405.00	59519.63					
	203									0.06304	0.61775

Table D-1. (continued) Carbon adsorption breakthrough curve of ethyl acetate. Influent concentration (C_{in}) = 0.10 M, GAC = 400 g.

No.	Initial time	Time usage (min.)	Flow Rate (ml/min.)	Average flow rate (ml/min.)	Volume of water treated (ml)	Cumulative volume of water treated (ml)	Effluent Conc. (M) C_{out}	C_{out}/C_{in}
204	7:15	5	76.0	77.00	385.00	59904.63	0.06506	0.63758
	7:20	5	76.0	76.00	380.00	60284.63		
	7:25	5	71.0	73.50	367.50	60652.13		
	7:30	5	70.0	70.50	352.50	61004.63		
	7:35	5	66.0	68.00	340.00	61344.63		
	7:40	5	63.0	64.50	322.50	61667.13		
	7:45	5	60.0	61.50	307.50	61974.63		
205	7:50	5	58.0	59.00	295.00	62269.63	0.06510	0.63797
	7:55	5	54.0	56.00	280.00	62549.63		
	8:00	5	53.0	53.50	267.50	62817.13		
	8:05	5	50.0	51.50	257.50	63074.63		
	8:10	5	46.0	48.00	240.00	63314.63		
	8:15	5	42.0	44.00	220.00	63534.63		
	8:20	5	40.0	41.00	205.00	63739.63		
206	8:25	5	37.0	38.50	192.50	63932.13	0.07048	0.69067
	8:30	5	24.0	30.50	152.50	64084.63		
	8:35	5	100.0		0.00	64084.63		
	8:40	5	100.0	100.00	500.00	64584.63		
	8:45	5	95.0	97.50	487.50	65072.13		
	8:50	5	91.0	93.00	465.00	65537.13		
	8:55	5	88.0	89.50	447.50	65984.63		
207	9:00	5	80.0	84.00	420.00	66404.63	0.07245	0.70996
	9:05	5	77.0	78.50	392.50	66797.13		
	9:10	5	71.0	74.00	370.00	67167.13		
	9:15	5	67.0	69.00	345.00	67512.13		
	9:20	5	62.0	64.50	322.50	67834.63		
	9:25	5	60.0	61.00	305.00	68139.63		

Table D-1. (continued) Carbon adsorption breakthrough curve of ethyl acetate. Influent concentration (C_{in}) = 0.10 M, GAC = 400 g.

No.	Initial time	Time usage (min.)	Flow Rate (ml/min.)	Average flow rate (ml/min.)	Volume of water treated (ml)	Cumulative volume of water treated (ml)	Effluent Conc. (M) C_{out}	C_{out}/C_{in}
208	9:30	5	54.0	57.00	285.00	68424.63	0.07312	0.71651
	9:35	5	50.0	52.00	260.00	68684.63		
	9:40	5	46.0	48.00	240.00	68924.63		
	9:45	5	40.0	43.00	215.00	69139.63		
	9:50	5	36.0	38.00	190.00	69329.63		
	9:55	5	31.0	33.50	167.50	69497.13		
209	10:00	5	24.0	27.50	137.50	69634.63	0.05851	0.57335
	10:02	2	104.0		0.00	69634.63		
	10:05	5	88.0	96.00	480.00	70114.63		
	10:15	5	84.0	86.00	430.00	70544.63		
	10:20	5	81.0	82.50	412.50	70957.13		
	10:25	5	70.0	75.50	377.50	71334.63		
210	10:30	5	70.0	70.00	350.00	71684.63	0.07324	0.71777
	10:35	5	64.0	67.00	335.00	72019.63		
	10:40	5	64.0	64.00	320.00	72339.63		
	10:45	5	58.0	61.00	305.00	72644.63		
	10:50	5	54.0	56.00	280.00	72924.63		
	10:55	5	52.0	53.00	265.00	73189.63		
211	11:00	5	50.0	51.00	255.00	73444.63	0.07451	0.73019
	11:05	5	44.0	47.00	235.00	73679.63		
	11:10	5	41.0	42.50	212.50	73892.13		
	11:15	5	35.0	38.00	190.00	74082.13		
	11:20	5	32.0	33.50	167.50	74249.63		
	11:25	5	30.0	31.00	155.00	74404.63		
212	11:30	5	26.0	28.00	140.00	74544.63	0.06051	0.59301
	11:35	5	126.0		0.00	74544.63		
	11:40	5	117.0	121.50	607.50	75152.13		

Table D-1. (continued) Carbon adsorption breakthrough curve of ethyl acetate. Influent concentration (C_{in}) = 0.10 M, GAC = 400 g.

No.	Initial time	Time usage (min.)	Flow Rate (ml/min.)	Average flow rate (ml/min.)	Volume of water treated (ml)	Cumulative volume of water treated (ml)	Effluent Conc. (M) C_{out}	C_{out}/C_{in}
213	11:44	4	138.0	127.50	510.00	75662.13	0.07497	0.73465
	11:45	1	117.6	127.80	127.80	75789.93		
	11:49	4	117.6	117.60	470.40	76260.33		
	11:50	1	84.0	100.80	100.80	76361.13		
	11:55	5	76.0	80.00	400.00	76761.13		
	12:00	5	71.0	73.50	367.50	77128.63		
	12:05	5	66.0	68.50	342.50	77471.13		
	12:10	5	61.0	63.50	317.50	77788.63		
	12:15	5	54.0	57.50	287.50	78076.13		
	12:20	5	52.0	53.00	265.00	78341.13		
214	12:25	5	47.0	49.50	247.50	78588.63	0.06990	0.68496
	12:30	5	46.0	46.50	232.50	78821.13		
	12:35	5	26.0	36.00	180.00	79001.13		
	12:40	5	110.4		0.00	79001.13		
	12:45	5	100.0	105.20	526.00	79527.13		
	12:50	5	46.0	73.00	365.00	79892.13		
	12:55	5	44.0	45.00	225.00	80117.13		
215	13:00	5	42.0	43.00	215.00	80332.13	0.06641	0.65075
	13:05	5	40.0	41.00	205.00	80537.13		
	13:10	5	38.0	39.00	195.00	80732.13		
	13:15	5	38.0	38.00	190.00	80922.13		
	13:20	5	38.0	38.00	190.00	81112.13		
	13:25	5	64.0		0.00	81112.13		
	13:30	5			0.00	81112.13		
	13:35	5	48.0		0.00	81112.13		
	13:36	1	63.0	55.50	55.50	81167.63		
	13:40	5	68.0	65.50	327.50	81495.13		

Table D-1. (continued) Carbon adsorption breakthrough curve of ethyl acetate. Influent concentration (C_{in}) = 0.10 M, GAC = 400 g.

No.	Initial time	Time usage (min.)	Flow Rate (ml/min.)	Average flow rate (ml/min.)	Volume of water treated (ml)	Cumulative volume of water treated (ml)	Effluent Conc. (M) C_{out}	C_{out}/C_{in}
216	13:45	5	62.0	65.00	325.00	81820.13	0.06818	0.66815
	13:50	5	59.0	60.50	302.50	82122.63		
	13:55	5	54.0	56.50	282.50	82405.13		
	14:00	5	50.0	52.00	260.00	82665.13		
	14:05	5	46.0	48.00	240.00	82905.13		
	14:10	5	40.0	43.00	215.00	83120.13		
	14:15	5	34.0	37.00	185.00	83305.13		
	14:17	2	79.0		0.00	83305.13		
217	14:20	3	79.0	79.00	237.00	83542.13	0.06743	0.66084
	14:25	5	73.0	76.00	380.00	83922.13		
	14:30	5	72.0	72.50	362.50	84284.63		
	14:35	5	67.0	69.50	347.50	84632.13		
	14:40	5	66.0	66.50	332.50	84964.63		
	14:45	5	62.0	64.00	320.00	85284.63		
	14:50	5	62.0	62.00	310.00	85594.63		
	14:55	5	58.0	60.00	300.00	85894.63		
218	15:00	5	54.0	56.00	280.00	86174.63	0.07590	0.74378
	15:05	5	52.0	53.00	265.00	86439.63		
	15:10	5	49.0	50.50	252.50	86692.13		
	15:15	5	46.0	47.50	237.50	86929.63		
	15:20	5	42.0	44.00	220.00	87149.63		
	15:25	5	41.0	41.50	207.50	87357.13		
	15:30	5	40.0	40.50	202.50	87559.63		
	15:34	4	124.5		0.00	87559.63		
219	15:40	5	114.0	119.25	596.25	88155.88	0.05963	0.58433
	15:45	5	105.0	109.50	547.50	88703.38		
	15:50	5	108.0	106.50	532.50	89235.88		

Table D-1. (continued) Carbon adsorption breakthrough curve of ethyl acetate. Influent concentration (C_{in}) = 0.10 M, GAC = 400 g.

No.	Initial time	Time usage (min.)	Flow Rate (ml/min.)	Average flow rate (ml/min.)	Volume of water treated (ml)	Cumulative volume of water treated (ml)	Effluent Conc. (M) C_{out}	C_{out}/C_{in}
220	15:55	5	93.0	100.50	502.50	89738.38	0.06209	0.60844
	16:00	5	99.0	96.00	480.00	90218.38		
	16:05	5	102.0	100.50	502.50	90720.88		
	16:10	5	78.0	90.00	450.00	91170.88		
	16:15	5	81.0	79.50	397.50	91568.38		
	16:20	5	69.0	75.00	375.00	91943.38		
221	16:25	5	69.0	69.00	345.00	92288.38	0.07481	0.73307
	16:30	5	60.0	64.50	322.50	92610.88		
	16:33	3	189.0		0.00	92610.88		
	16:34	1	114.0	151.50	151.50	92762.38		
	16:36	2	78.0	96.00	192.00	92954.38		
	16:40	4	72.0	75.00	300.00	93254.38		
	16:45	5	69.0	70.50	352.50	93606.88		
	16:50	5	66.0	67.50	337.50	93944.38		
	16:55	5	60.0	63.00	315.00	94259.38		
	17:00	5	60.0	60.00	300.00	94559.38		
222	17:05	5	60.0	60.00	300.00	94859.38	0.07316	0.71693
	17:10	5	60.0	60.00	300.00	95159.38		
	17:15	5	54.0	57.00	285.00	95444.38		
	17:20	5	54.0	54.00	270.00	95714.38		
	17:25	5	54.0	54.00	270.00	95984.38		
	17:30	5	51.0	52.50	262.50	96246.88		
223	17:35	5	51.0	51.00	255.00	96501.88	0.06850	0.67132
	17:40	5	51.0	51.00	255.00	96756.88		
	17:45	5	42.0	46.50	232.50	96989.38		
224	17:50	5	42.0	42.00	210.00	97199.38	0.06532	0.64012
	6:33		72.0					

Table D-1. (continued) Carbon adsorption breakthrough curve of ethyl acetate. Influent concentration (C_{in}) = 0.10 M, GAC = 400 g.

No.	Initial time	Time usage (min.)	Flow Rate (ml/min.)	Average flow rate (ml/min.)	Volume of water treated (ml)	Cumulative volume of water treated (ml)	Effluent Conc. (M) C_{out}	C_{out}/C_{in}
225	6:37	4	66.0	69.00	276.00	97475.38	0.06827	0.66900
	6:40	3	66.0	66.00	198.00	97673.38		
	6:42	2	129.0	66.00	132.00	97805.38		
	6:45	3	126.0	127.50	382.50	98187.88		
	6:50	5	84.0	126.00	630.00	98817.88		
	6:55	5	83.0	83.50	417.50	99235.38		
	7:00	5	79.0	81.00	405.00	99640.38		
	7:05	5	75.0	77.00	385.00	100025.38		
	7:10	5	72.0	73.50	367.50	100392.88		
	7:15	5	68.0	70.00	350.00	100742.88		
226	7:20	5	64.0	66.00	330.00	101072.88	0.07318	0.71715
	7:25	5	60.0	62.00	310.00	101382.88		
	7:30	5	55.0	57.50	287.50	101670.38		
	7:35	5	53.0	54.00	270.00	101940.38		
	7:40	5	50.0	51.50	257.50	102197.88		
	7:45	5	48.0	49.00	245.00	102442.88		
	7:50	5	45.0	46.50	232.50	102675.38		
	7:53	3	150.5	150.50	451.50	103126.88		
	7:54	1	60.0	60.00	60.00	103186.88		
	7:55	1	49.0	49.00	49.00	103235.88		
227	8:00	5	50.0	49.50	247.50	103483.38	0.06359	0.62321
	8:05	5	46.0	48.00	240.00	103723.38		
	8:06	1	66.0	66.00	66.00	103789.38		
	8:10	4	47.0	66.00	264.00	104053.38		
	8:15	5	68.0	66.00	330.00	104383.38		
	8:20	5	66.0	66.00	330.00	104713.38		
	8:25	5	64.0	66.00	330.00	105043.38		

Table D-1. (continued) Carbon adsorption breakthrough curve of ethyl acetate. Influent concentration (C_{in}) = 0.10M, GAC = 400 g.

No.	Initial time	Time usage (min.)	Flow Rate (ml/min.)	Average flow rate (ml/min.)	Volume of water treated (ml)	Cumulative volume of water treated (ml)	Effluent Conc. (M) C_{out}	C_{out}/C_{in}
228	8:30	5	60.0	66.00	330.00	105373.38	0.06787	0.66506
	8:35	5	59.0	66.00	330.00	105703.38		
	8:40	5	56.0	66.00	330.00	106033.38		
	8:45	5	54.0	66.00	330.00	106363.38		
	8:50	5	51.0	66.00	330.00	106693.38		
	8:55	5	50.0	66.00	330.00	107023.38		
229	9:00	5	46.0	66.00	330.00	107353.38	0.06833	0.66963
	9:05	5	44.0	66.00	330.00	107683.38		
	9:10	5	42.0	66.00	330.00	108013.38		
	9:15	5	40.0	66.00	330.00	108343.38		
	9:20	5	40.0	66.00	330.00	108673.38		
	9:22	2	90.0	90.00	180.00	108853.38		
230	9:25	3	90.0	90.00	270.00	109123.38	0.06833	0.66963
	9:30	5	82.0	86.00	430.00	109553.38		
	9:35	5	82.0	82.00	410.00	109963.38		
	9:40	5	84.0	83.00	415.00	110378.38		
	9:45	5	78.0	81.00	405.00	110783.38		
	9:50	5	71.0	74.50	372.50	111155.88		
231	9:55	5	66.0	68.50	342.50	111498.38	0.09190	0.90062
	10:00	5	64.0	65.00	325.00	111823.38		
	10:05	5	61.0	62.50	312.50	112135.88		
	10:10	5	57.0	59.00	295.00	112430.88		
	10:15	5	54.0	55.50	277.50	112708.38		
	10:20	5	54.0	54.00	270.00	112978.38		
232	10:25	5	51.0	52.50	262.50	113240.88	0.08177	0.80135
	10:30	5	48.0	49.50	247.50	113488.38		
	10:35	5	48.0	48.00	240.00	113728.38		

Table D-1. (continued) Carbon adsorption breakthrough curve of ethyl acetate. Influent concentration (C_{in}) = 0.10 M, GAC = 400 g.

No.	Initial time	Time usage (min.)	Flow Rate (ml/min.)	Average flow rate (ml/min.)	Volume of water treated (ml)	Cumulative volume of water treated (ml)	Effluent Conc. (M) C_{out}	C_{out}/C_{in}
233	10:40	5	44.0	46.00	230.00	113958.38	0.08531	0.83603
	10:41	1	96.0	96.00	96.00	114054.38		
	10:45	4	76.0	74.00	296.00	114350.38		
	10:50	5	72.0	69.50	347.50	114697.88		
	10:55	5	67.0	67.50	337.50	115035.38		
	11:00	5	68.0	66.50	332.50	115367.88		
	11:05	5	65.0	64.50	322.50	115690.38		
	11:10	5	64.0	62.00	310.00	116000.38		
	11:15	5	60.0	59.50	297.50	116297.88		
	11:20	5	59.0	58.00	290.00	116587.88		
234	11:25	5	57.0	56.00	280.00	116867.88	0.10591	1.03782
	11:30	5	55.0	77.00	385.00	117252.88		
	11:35	5	99.0	99.00	495.00	117747.88		
	11:40	5	86.0	92.50	462.50	118210.38		
	11:45	5	80.0	83.00	415.00	118625.38		
	11:50	5	75.0	77.50	387.50	119012.88		
	11:55	5	66.0	70.50	352.50	119365.38		
235	12:00	5	60.0	63.00	315.00	119680.38	0.139560	0.99985
	12:10	10	35.0	35.00	350.00	120030.38		
236	12:20	10	31.0	33.00	330.00	120360.38	0.132790	0.95135
	12:30	10	31.0	31.00	310.00	120670.38		
237	12:40	10	29.5	30.25	302.50	120972.88	0.143210	1.02600
	12:50	10	29.5	29.50	295.00	121267.88		
	13:00	10	28.0	28.75	287.50	121555.38		
	13:10	10	26.0	27.00	270.00	121825.38		
	13:20	10	26.0	26.00	260.00	122085.38		
	13:20	10	25.0	25.50	255.00	122340.38		

Table D-1. (continued) Carbon adsorption breakthrough curve of ethyl acetate. Influent concentration (C_{in}) = 0.10 M, GAC = 400 g.

No.	Initial time	Time usage (min.)	Flow Rate (ml/min.)	Average flow rate (ml/min.)	Volume of water treated (ml)	Cumulative volume of water treated (ml)	Effluent Conc. (M) C_{out}	C_{out}/C_{in}
238	13:30	10	24.5	24.75	247.50	122587.88	0.139890	1.00222
	13:40	10	23.0	23.75	237.50	122825.38		
	13:50	10	23.0	23.00	230.00	123055.38		
	14:00	10	22.5	22.75	227.50	123282.88		
	14:10	10	21.5	22.00	220.00	123502.88		
	14:20	10	21.0	21.25	212.50	123715.38		
	14:30	10	19.0	20.00	200.00	123915.38		
239	14:40	10	18.5	18.75	187.50	124102.88	0.139590	1.00007
	14:50	10	18.0	18.25	182.50	124285.38		
	15:00	10	17.0	17.50	175.00	124460.38		
	15:10	10	16.0	16.50	165.00	124625.38		
	15:20	10	15.5	15.75	157.50	124782.88		
	15:30	10	15.0	15.25	152.50	124935.38		
	15:40	10	14.0	14.50	145.00	125080.38		
240	15:50	10	14.0	14.00	140.00	125220.38	0.149060	1.06791
	16:00	10	13.0	13.50	135.00	125355.38		
	16:10	10	10.5	11.75		125355.38		
	16:20	10	10.5	10.50	105.00	125460.38		
	16:30	5	27.0	10.50		125460.38		
	16:40	5	24.5	25.75	128.75	125589.13		
	16:50	5	38.0	24.50		125589.13		
241	17:00	5	30.5	34.25	171.25	125760.38	0.124080	0.88895
	17:10	10	30.5	30.50	305.00	126065.38		
	17:20	10	30.5	30.50	305.00	126370.38		
	17:30	10	29.5	30.00	300.00	126670.38		
	17:40	10	29.0	29.25	292.50	126962.88		
	17:50	10	29.0	29.00	290.00	127252.88		

Table D-1. (continued) Carbon adsorption breakthrough curve of ethyl acetate. Influent concentration (C_{in}) = 0.10 M, GAC = 400 g.

No.	Initial time	Time usage (min.)	Flow Rate (ml/min.)	Average flow rate (ml/min.)	Volume of water treated (ml)	Cumulative volume of water treated (ml)	Effluent Conc. (M) C_{out}	C_{out}/C_{in}
242	18:00	10	26.3	27.65	276.50	127529.38	0.147120	1.05401
	18:10	10	26.3	26.30	263.00	127792.38		

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BIOGRAPHY

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