Study of Adsorption and Desorption of Industrial Pollutant Unto Activated Carbon

By

Hestie Leonie Adesine

Dissertation submitted in partial fulfillment of

the requirements for the

Bachelor of Engineering (Hons)

(Chemical Engineering)

January 2004

Universiti Teknologi PETRONAS
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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
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Approved by,

____
(Mdm Ruzaimah Nik Mohamad Kamil)
Supervisor

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
January 2004

CERTIFICATION OF ORIGINALITY

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

HESTIE LEONIE ADESINE

ABSTRACT

The main objective of this research is to study the factor that influence adsorption and desorption of phenol unto activated carbons on types of activated carbon used (granular and powered activated carbon). Activated carbons are commonly used for the removal of pollutants from waste effluents. The adsorption onto activated carbons from water is a complex process, influenced by the activated carbon surface structure and chemistry, and the adsorbate structure, i.e. charge, polarity, size and shape. It is therefore necessary to analyse the factors, which influence the adsorption and desorption onto activated carbons e.g. types of activated carbons and adsorbates, ionic strength, surface charge, pH etc. In the scope of study, this study is very feasible as the experiments that going to be conducted can be done. This is because of the equipments and materials related to the study are available in the laboratories. Methodology will be consisting of literature review, laboratory work, analysis of laboratory result and documentation. Experimental works will include the 24 hrs adsorption of activated carbons in various phenol solution, and 3 days desorption of activated carbons in 0.5M NaOH. All experimental works had been successfully conducted. Based on the correlation coefficient, r^2, the best fit isotherm for adsorption is Langmuir isotherm, and the best fit for desorption is Freudlich isotherm. The types of activated carbon do affect the adsorption and desorption capacities. Where, powdered activated carbon (PAC) has higher volume of mesopores than granular activated carbon (GAC), will has higher adsorption capacities compare to GAC. The experimental results do not tally with the theoretical result due to the other control factor that influences the adsorption capacities, such as the polarity, surface charge and size. For desorption, GAC has higher desorption capacities compare to PAC. This can be explained by the large surface area of pores in GAC. It is recommended that a further study on the functional group attraction to the activated carbon in desorption to be conducted in the future. This in order to obtain a better results and explanation compare to the one conducted in this study. As the conclusion, all of the research objectives had been achieved.

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Regards are expressed to my parents for their constant blessing and support throughout the trying times of this project.

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Adsorption on activated carbon is of environmental significant because in many cases it is the method of choice for the removal of contaminants from air and water. Adsorption is a surface process that exemplified by the concentration of gases, vapors, or solutes from solution at or near the surfaces of solids, or within surface cracks, pores, or crevices of nanometer dimensions. Activated carbons have extremely high surface areas and porosity; the high surface areas magnify the extent of adsorption, and the porosity increases the (exothermic) energy of adsorption. The amount of adsorption of a given single component on a given activated carbon at equilibrium may vary from near zero to about 50% by weight; it depends on the nature of the substance adsorbed (adsorbate), the partial pressure (or concentration), the temperature, and the presence of any other possibly competing substances. For a given single component on a given carbon, a plot of the amount adsorbed against the partial pressure or concentration at constant temperature is known as an adsorption isotherm.

In this study of adsorption and desorption unto activated carbon, the type of industrial pollutant used will be phenol. Although, phenol (C_6H_5OH) has been detected in decaying organic matter and animal urine, its presence in a surface stream is attributed to industrial pollution. Petroleum refineries, coe plants, and resin plants are major industrial phenolic waste sources. Phenolic compounds and their derivatives are used in coating, solvents, plastics, explosives, fertilizer, textiles, pharmaceuticals, soap, and dyes.

Treatment methods for phenol removal include biological (activated sludge, trickling filter, oxidation pond and lagoon); chemical oxidation (air, chlorine, chlorine dioxide, ozone, and hydrogen peroxide); physical (activated carbon adsorption, solvent extraction, and ion exchange); and physicochemical (incineration and electrolytic oxidation).

1.2 Problem Statement

Activated carbons are commonly used for the removal of pollutants from waste effluents. The adsorption onto activated carbons from water is a complex process, influenced by the activated carbon surface structure and chemistry, and the adsorbate structure, i.e. charge, polarity, size and shape. It is therefore necessary to analyse the factors, which influence the adsorption and desorption onto activated carbons e.g. types of activated carbons and adsorbates, ionic strength, surface charge, pH etc

1.3 Objectives and Scope of Study

1.3.1 Objectives

From the problem statement the main objectives of the project are identified as follows: -

I. To study the factor that influence adsorption and desorption of phenol unto activated carbons on types of activated carbon used (granular and powered activated carbon).
II. To develop a most appropriate relationship between the factor study with the effect to adsorption and desorption, by choosing in the best fit isotherm (Freudlich Isotherm and Langmuir Isotherm).
III. To conduct experimental works to obtain related results to support this study.

1.3.2 Scope of Study

This research project will focus on the effects of different types of activated carbons to adsorption and desorption of activated carbons for phenol. There are two types of activated carbons used; Granular activated carbon (GAC) and Powdered activated carbon (PAC).

In order to achieve the objective of the study, most of the results will come from the experiments analysis. There laboratory work is very important in this study. Since generally all the equipment can be obtain from the laboratories. Therefore, this will make this research study feasible to be conducted.

CHAPTER 2

LITERATURE REVIEW AND THEORY

2.1 Activated Carbon

The most practicable available method for removing refractory organics is by adsorbing them on activated carbon. Adsorption is the accumulation of materials at an interface. The interface, in the case of wastewater and activated carbon, is the liquid/solid boundary layer. Organic materials accumulate at the interface because of physical binding of the molecules to the solid surface. Carbon is activated by heating in the absence of oxygen. The activation process results in the formation of many pores within each carbon particle. Since adsorption is a surface phenomena, the greater the surface area of the carbon, the greater its capacity to hold organic material. The vast areas of the walls within these pores account for most of the total surface area of the carbon, which makes it so effective in removing organics.

2.2 Adsorption

2.2.1 Definition

Adsorption is a process to remove components present in low concentrations in nonadsorbing solvents or gases and to separate the components in gas or liquid mixtures by selective adsorption on solids, followed by desoprtion process to regenerate the adsorbents.

Adsorption can be applied in both gaseous and liquid separations. It is often used to remove odours from gaseous streams. Application in liquid stream is used to remove the taste and odour from water, decolourise petroleum products and aqueous sugar solutions, and treat the industrial wastewater containing organic, dye and heavy metal ions.

2.2.2 Theory

Adsorption of a material occurs at the surface since it reduces the imbalance of attractive forces, and, therefore, the surface free energy of the heterogeneous system.

Two phenomena are observed; physical adsorption and chemical adsorption. Nevertheless, physical adsorption differs from chemisorption according to the parameters listed in the table below:

Table 2.1: Parameters of physical adsorption and chemisorption

Parameter	**Physical adsorption**	**Chemisorption**
• Heat of adsorption	• Low	• High
• Specificity	• Not site specific	• Highly site specific
• Nature of adsorbed phase	• Monolayer or multilayer, no dissociation of adsorbed species	• Monolayer only, may involve dissociation
• Temperature range	• Only significant at low temperatures	• Possible over wide range of temperature

2.2.3 Kinetics

Two important properties in an adsorption system using activated carbon as the adsorbent includes the adsorptive capacity of a given amount of carbon for a particular solute and the adsorption rate at which that solute is taken out of solution.

Adsorption rate depends on several factors mainly the size and porous structure of activated carbon particles, size and structure of the solute molecule, concentration of solute in solution, and temperature of solution.

The surface chemical properties also play an important role for activated carbon. Factors including the surface area of the activated carbon, pore size of carbon, solubility of solute in aqueous solution, pH and temperature will affect the adsorptive capacity of the adsorbents. The adsorption process on a porous adsorbent usually proceeds in three consecutive steps ; (1)Transport of solute from the bulk of the solution to the outer surface of the film surrounding the particle-bulk transport, (2)Transport of solute within the film- film transport, (3)Transport in the interior of the particle – intraparticle transport.

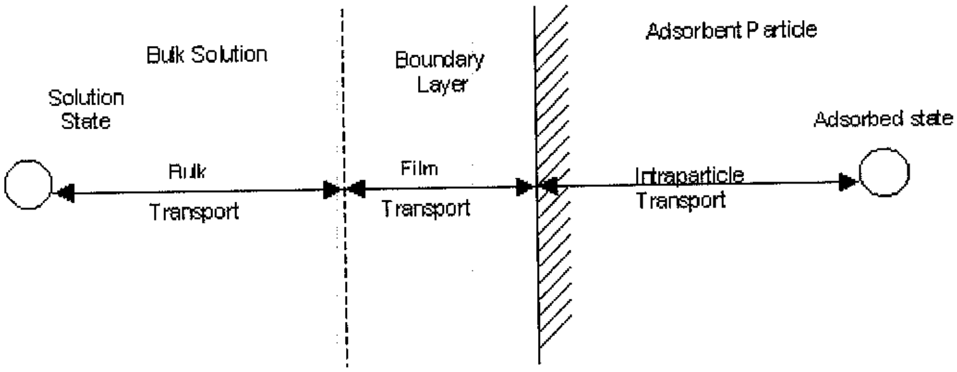


Figure 2.1: Schematic representation of the series of resistance to adsorption

Thus if C_o is the initial concentration and C_e is the concentration of solute after equilibrium and m is the mass of adsorbent present, then amount of solute adsorbed per unit weight of adsorbent is given as:

$$q_e = \frac{(C_o - C_e) \times V}{m}$$

where V is the volume of solution used in the batch.

2.2.4 Equilibrium

The relationship between the quantity of adsorbate per unit of adsorbent, q_e, and the equilibrium concentration of adsorbate in solution, C_e, is called an adsorption isotherm. The equilibrium-adsorbed amount on the adsorbent is a function of both the characteristics and concentration of the adsorbate depending on the temperature.

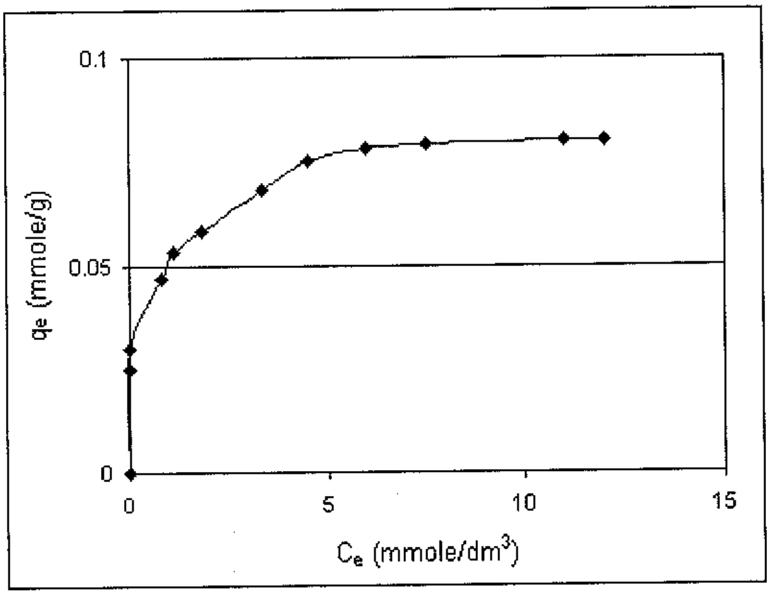


Figure 2.2: An example of a typical adsorption isotherm curve

Equations that are commonly used to describe the experimental adsorption data are those developed by Freundlich, Langmuir, and Braunauer.

Freundlich Isotherm - This isotherm is an empirical expression and has no physical basis, hence the equilibrium relationship proposed by Freundlich is only valid when the adsorption is a purely physical process without any change in the configuration of the molecules in the adsorbed state. The equilibrium equation of this model is as follows:

$$q_e = K_F * C_e^{1/n}$$

where q_e = equilibrium adsorbed amount on the adsorbent, C_e = equilibrium concentration, K_F and n = empirical constants depending on the nature of adsorbent and adsorbate.

The constant K_F is an approximate indicator of adsorption capacity, while *1/n* is a function of the strength of adsorption, i.e. mechanism of adsorption. The constants in the model can be obtained by linearization of the above equation:

$$\ln q_e = \ln K_F + \frac{1}{n} \ln C_e$$

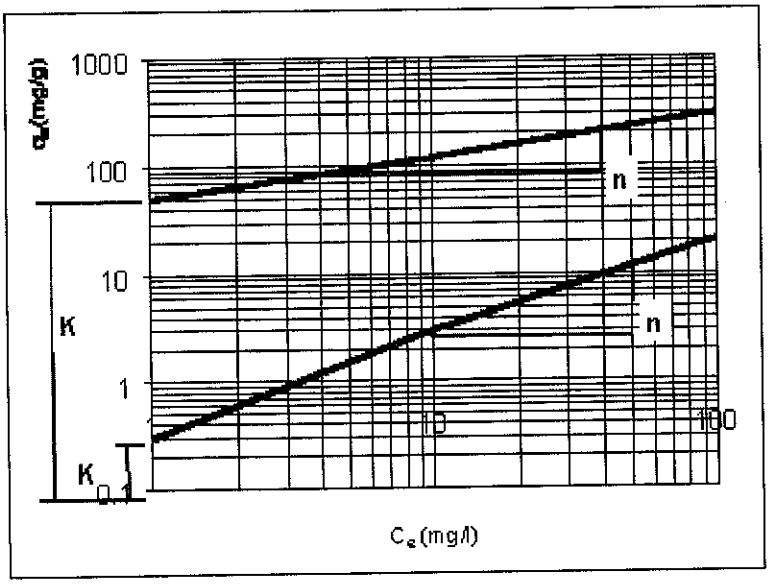


Figure 2.3: Typical Freundlich Fit

Langmuir Isotherm - The commonly written form of this model is:

$$q_e = \frac{q_0 b C_e}{1 + b C_e}$$

where q_o = saturation limit and b = a temperature dependent equilibrium constant.

The constant q_o corresponds to the surface concentration at monolayer coverage and represents the maximum value of q_e that can be achieved as C_e is increased. The constant b is related to the energy of adsorption and increases as the strength of the adsorption bond increases. In order to evaluate the Langmuir constants, a linearised from of the Langmuir equation is used:

$$\frac{1}{q_e} = \frac{1}{q_o b C_e} + \frac{1}{q_o}$$

A plot of $1/q_e$ versus $1/C_e$ will yield a straight line for data which fits the Langmuir expression. Hence, from the gradient $1/(q_o b)$ and intercept, $1/q_0$ the Langmuir constants can be calculated.

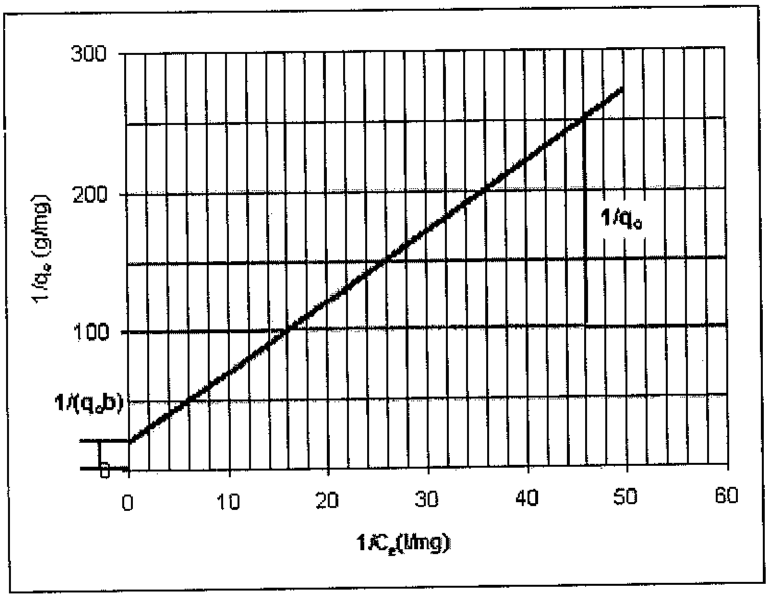


Figure 2.4: Typical Langmuir Fit

CHAPTER 3
METHODOLOGY

3.1 Procedure Identification

3.1.1 Material Required

a) Chemical

- Phenol (5 mg/L , 20 mg/L, 50 mg/L, 100 mg/L, 200 mg/L)
- 0.5M Sodium hydroxide
- 0.5M Hydrochloric acid

b) Activated Carbon

- Granular activated carbon (GAC-H300)
- Powdered activated carbon (PAC-R4, PAC-S4, PAC-S5)

3.1.2 Procedures

Step 1: Preparation of Activated Carbon

1. Activated carbon were dried in an oven at 110°C for 24 h
2. Kept in a desiccator until the samples reached room temperature

Step 2: Wavelength of Adsorbates

1. A known amount of phenol is inserted into a cuvette.
2. Phenol is then analyse with UV Spectrometer by setting the range of wavelength from 200nm to 500nm.
3. A graph will be obtained and the highest peak achieved will indicate the wavelength of the substance.

Step 3: Standard Adsorption Curve

1. Prepare 5 different concentration of phenol.
2. Insert a known concentration of phenol into a tube cell and test with UV Spectrometer.
3. Plot a graph of concentration of the phenol solution against absorbance.

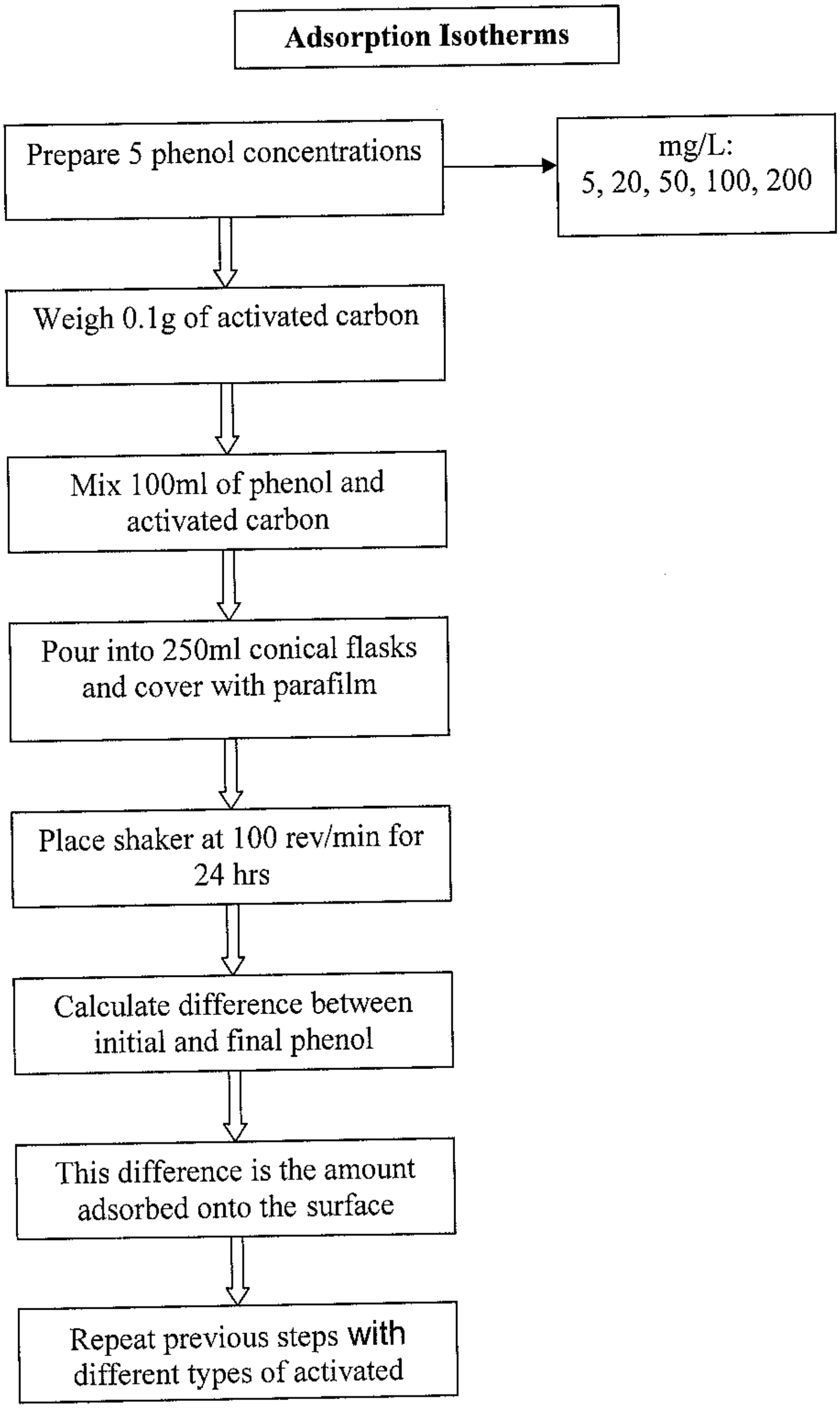
Step 4: Adsorption Isotherms

1. Prepare 5 different concentration of phenol.
2. Weigh 0.1g of the activated carbon.
3. Pour a 100ml of phenol and activated carbon into a 250ml conical flask and cover with parafilm.
4. Conical flasks were placed on a shaker at 100 rev/min.
5. Shake samples for 24 hrs and filter out the activated carbon.
6. Check the final concentration with UV Spectrometer.
7. The amount adsorb onto the surface was calculated from the difference between the initial and final phenol concentration.
8. Repeat steps 1- 6 by using different types of activated carbon.

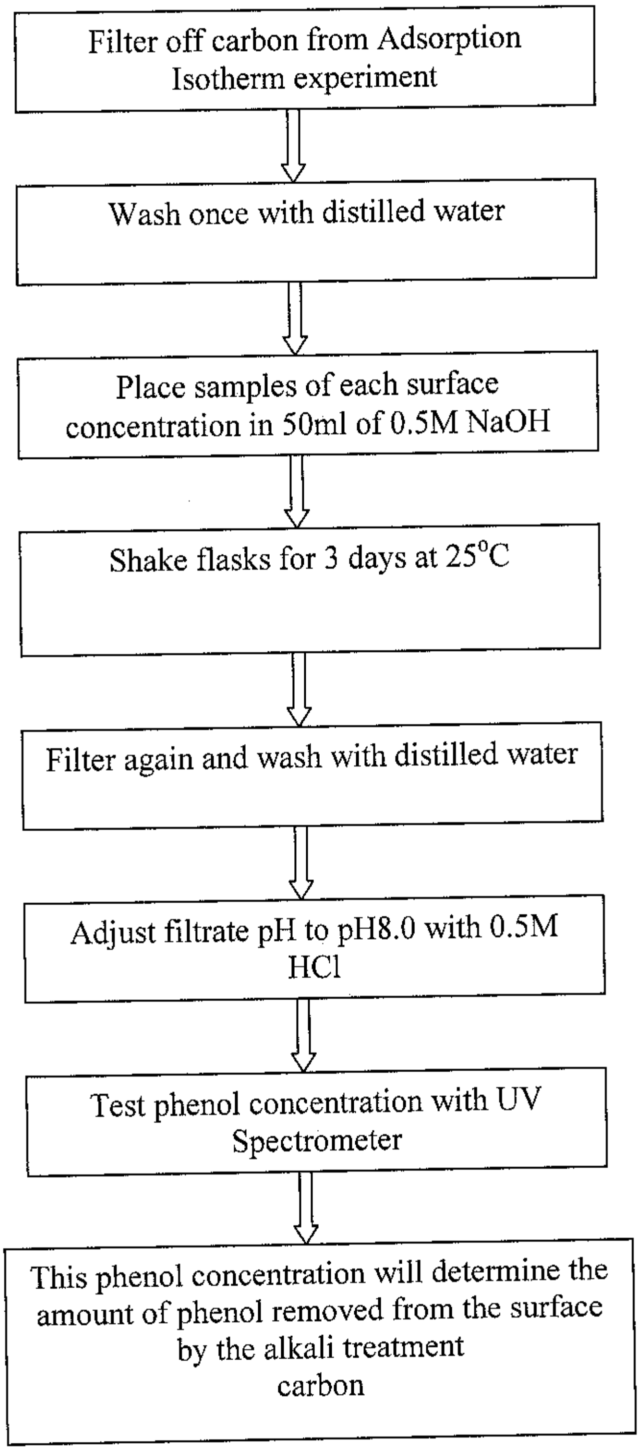
Step 5: Desorption Isotherm

1. From Adsorption Isotherm experiment, the carbon was filtered off and washed once with distilled water, samples of each surface concentration were placed in 50 cm^3 (50ml) of 0.5 M NaOH solution.
2. The flasks were shaken for 3 days at 25°C and again filtered and washed with distilled water.
3. The filtrate was adjusted to pH = 8.0 with 0.5M HCl.
4. Concentration is tested by using UV Spectrometer.

3.1.3 Flow chart



Adsorption Isotherms



3.2 Tools Required

a) UV/Vis Spectrometer

The UV/Vis spectrometer consists of a light source, a sample compartment, a diode-array detector, and a data acquisition computer. The sample compartment is between the light source and the detector. The spectrometer measures the amount of ultraviolet and visible light transmitted by a sample placed in the sample compartment. Typically liquid samples are used, contained in a transparent "cuvette" or "cell". A flow-through cell for the kinetics experiment is currently in the sample compartment, but another standard cuvette can easily be substituted for it. The sample compartment in our spectrometer is made for 1 cm cuvettes.

The wavelength at which a chemical absorbs light is a function of its electronic structure, so a UV/Vis spectrum can be used to identify some chemical species. For a particular chemical, the amount of the light absorbed is related to the amount of the chemical between the light source and the detector, so a UV/Vis spectrum can be used to quantify some chemical species. To use UV/Vis data for quantitation, "Transmittance" (T, the percentage of light transmitted by the sample) must be be converted to "Absorbance" (A = -log(T)). When 1 % of the light is transmitted (T=0.01), then Absorbance=2. When 100 % of the light is transmitted (T=1), then Absorbance=0. Our spectrometer will automatically record absorbance.

"Beer's Law" states that absorbance and concentration in solution are linearly related for a given chemical, so long as the length of the path through the solution is fixed. Actually, this linear dependence only holds below Absorbance=2. When less than 1 % of the light is transmitted (A > 2), the detector behaves non-linearly. A UV/Vis spectrum is only useful for quantifying chemical species after "calibration". A series of solutions of known concentration must be analyzed and their absorbances recorded. From this data, a mathematical relationship between absorbance and concentration can be determined.

CHAPTER 4

RESULTS AND DISCUSSION

In wastewater treatment, activated carbon is a powerful adsorbent because it has a large surface area and pore volume, which allows the removal of liquid-phase contaminants, including organic compounds, heavy metal ions and colors. An important cost factor in applying the adsorption treatment is the adsorption capacities of carbons for the compounds to be removed. The capacities of carbon for contaminant compounds are significant affected by the pore structures of activated carbon as well as the size of the adsorbate.

The purpose of this study focuses on comparing the liquid-phase adsorption characteristics of commercial activated carbons with different types of activated carbons and pore structures. In this case, two types of activated carbons were used; granular activated carbon and powdered activated carbon. Phenol which has molecular weight of 94 and estimated diameters of 0.62 nm was employed as the adsorbates in the adsorption experiments. This compound is used because phenol and its derivative are frequently encountered in wastewater treatment, and the capacity for phenol, thus, serves as an important indicator for the adsorption of small polar aromatic compounds.

4.1 Best Fit Isotherm

4.1.1 Adsorption Isotherms

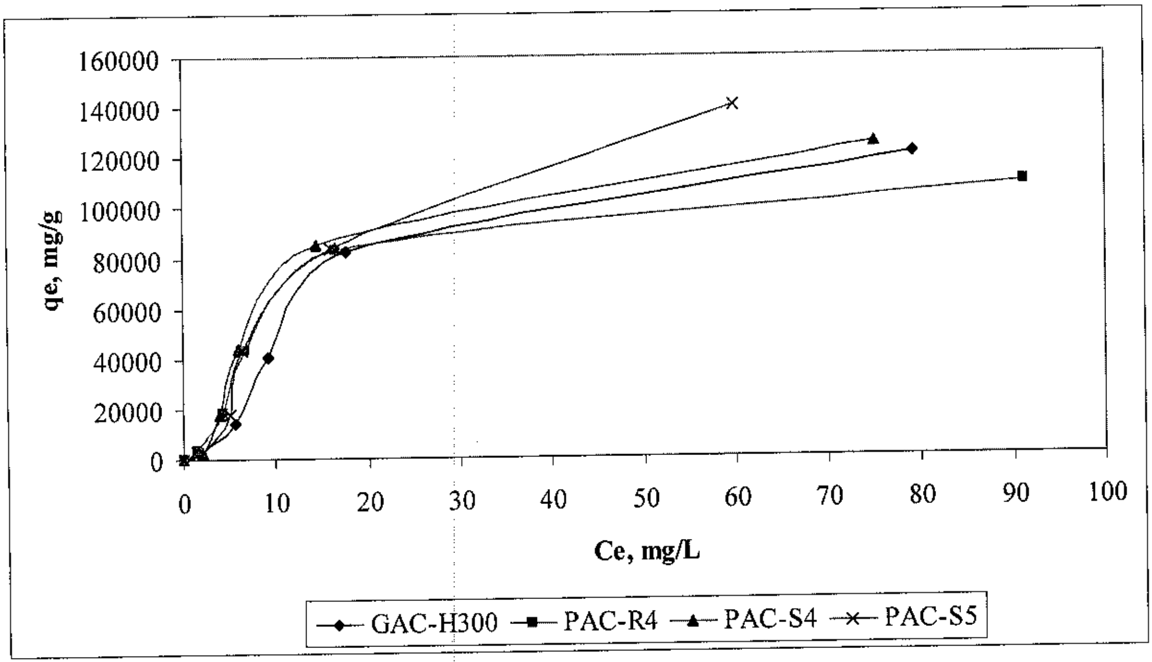


Figure 4.1: Phenol adsorption isotherm for 4 types of activated carbon, GAC-H300, PAC-R4, PAC-S4 and PAC-S5

Freudlich Isotherm

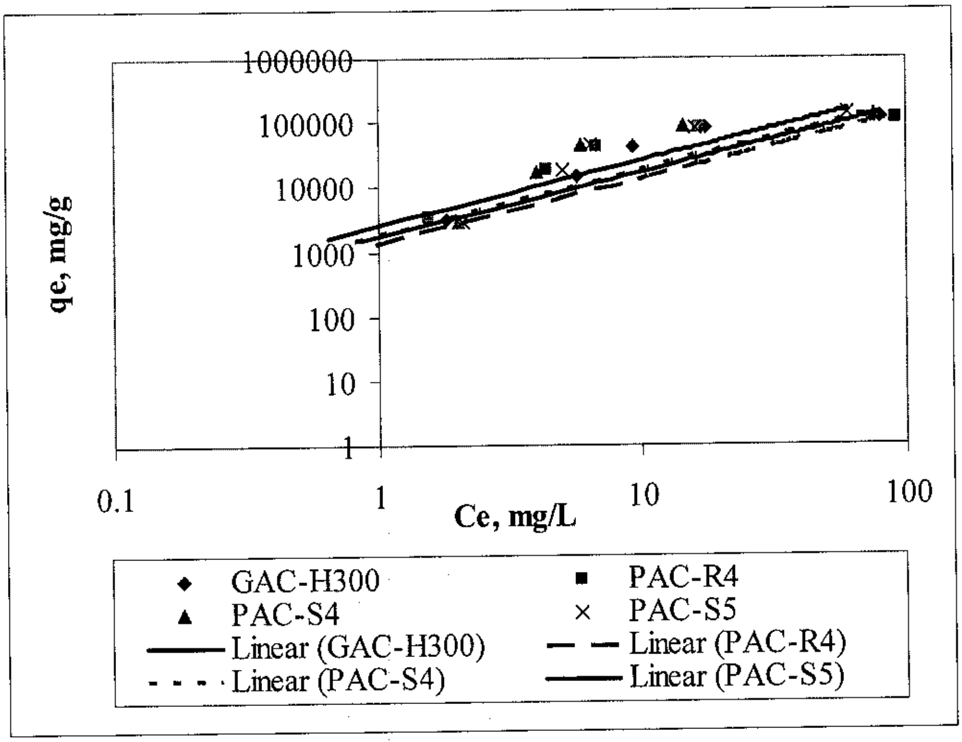


Figure 4.2: Freudlich fit for phenol adsorption isotherm for 4 types of activated carbon, GAC-H300, PAC-R4, PAC-S4 and PAC-S5

Langmuir Isotherm

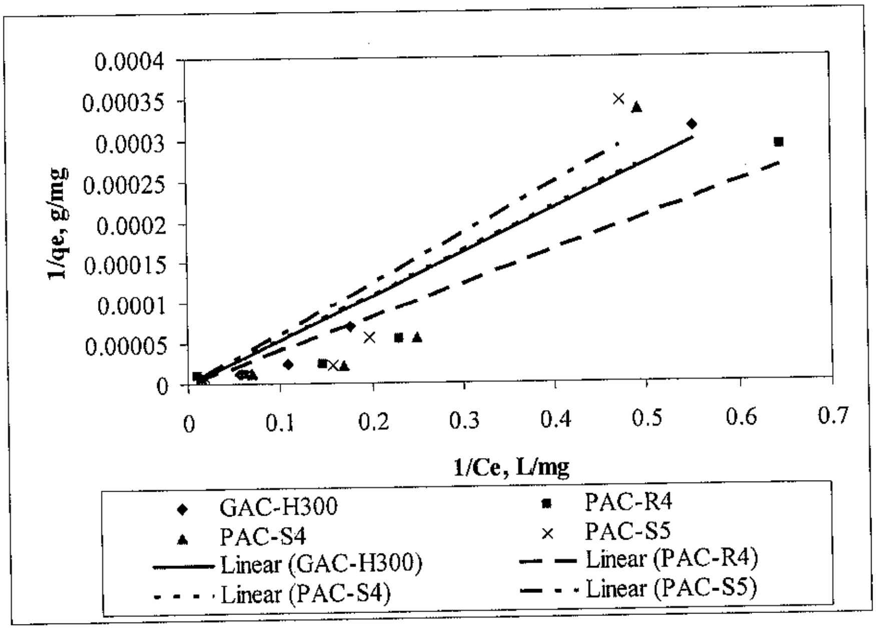


Figure 4.3: Langmuir fit for phenol adsorption isotherm for 4 types of activated carbon, GAC-H300, PAC-R4, PAC-S4 and PAC-S5

Figure 4.1 typically shows the adsorption isotherm of phenol at 20°C onto various activated carbons in aqueous solutions. In the range of equilibrium concentrations shown in *Figure 4.1*, the adsorption capacities of the carbons have the following order: S5 > S4 > H300 > R4. *Figure 4.2* and *Figure 4.3* show the adsorption isotherms gain from the experimental results. Adsorption isotherm is basically important to describe how solutes interact with adsorbents, and is critical in optimizing the use of adsorbents. The correlation of isotherm data by either theoretical or empirical equations is thus desired to practical operation. According to the data tabulated in *Table 4.1* (by comparing the correlation coefficient, r^2) it is expected that the best fit isotherm graph is Langmuir Isotherm.

Table 4.1: Correlation coefficient, r^2 for Freudlich Isotherm and Langmuir Isotherm for adsorption

Activated Carbon	Correlation coefficient, r^2	
	Freudlich Isotherm	**Langmuir Isotherm**
H300	0.7914	0.9844
R4	0.6812	0.9601
S4	0.7544	0.8606
S5	0.8699	0.9099

Two-parameter Langmuir equation: $q_e = \dfrac{q_0 b C_e}{1 + b C_e}$

where q_o = saturation limit and b = a temperature dependent equilibrium constant. The constant q_o corresponds to the surface concentration at monolayer coverage and represents the maximum value of q_e that can be achieved as C_e is increased. The constant b is related to the energy of adsorption and increases as the strength of the adsorption bond increases.

In order to evaluate the Langmuir constants, a linearised from of the Langmuir equation is used:

$$\frac{1}{q_e} = \frac{1}{q_o b C_e} + \frac{1}{q_o}$$

A plot of $1/q_e$ versus $1/C_e$ will yield a straight line for data which fits the Langmuir expression. Hence, from the gradient $1/(q_o b)$ and intercept, $1/q_0$ the Langmuir constants can be calculated. The parameters obtained for adsorption of solutes are listed in *Table 4.2*.

Table 4.2: Parameters of the Langmuir equation for adsorption of phenol at 20°C on various activated carbons

Activated Carbon	q_0	**b**	r^2
H300	50000	0.0333	0.9844
R4	50000	0.0400	0.9601
S4	20000	0.0714	0.8606
S5	20000	0.0625	0.9099

The fit is quite good under the concentration ranges studied (correlation coefficient, $r^2 > 0.8606$). It is seen from the tabulated data in *Table 4.2*, that the difference between adsorption capacity (q_0) of phenol unto all types of activated carbon studied cannot be seen clearly. However, based on the *Figure 4.3*, the monolayer adsorption capacities of the carbons have the following order: S5 > S4 > H300 > R4. This behavior shows the same order as in the typical isotherm (*Figure 4.1*). Theoretically, the adsorption capacity can be determine by considering that carbon adsorbers that posses a higher mesopores volume should be considered as a better option for adsorption in aqueous solutions. That is the following order should be obtained: PAC-S5 > PAC-S4 > PAC-R4 > GAC-H300. However, this may due to the other control factors influence the adsorption capacities. Other than that, from this isotherm it can be seen that PAC has better adsorption capacities compare to GAC.

4.1.2 Desorption Isotherm

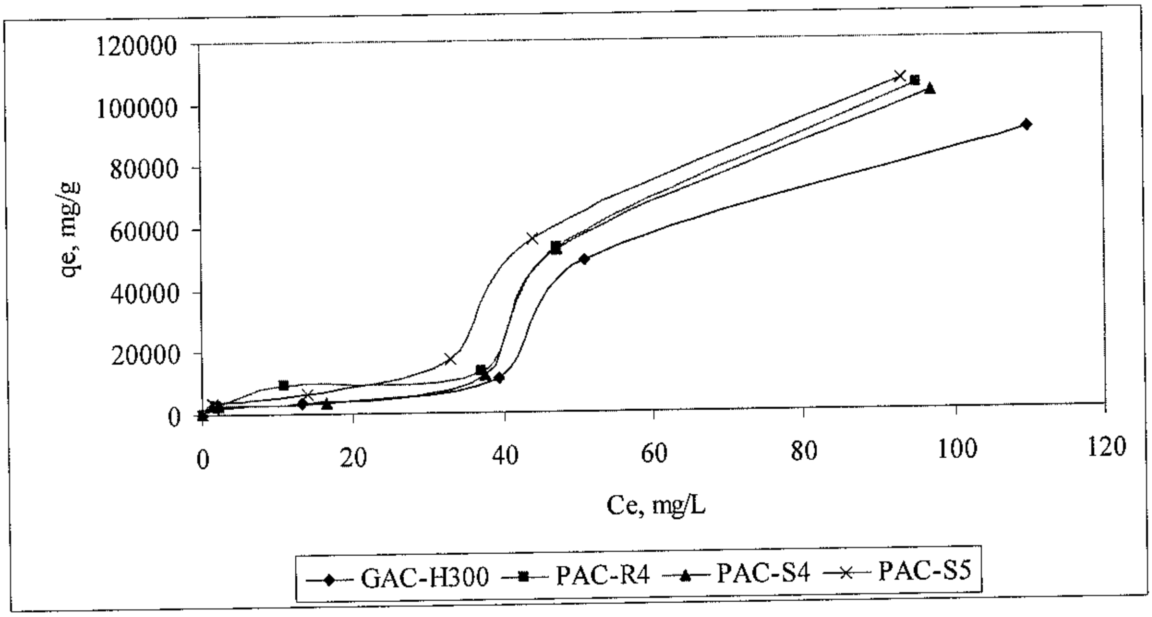


Figure 4.4: Phenol desorption isotherm for 4 types of activated carbon, GAC-H300, PAC-R4, PAC-S4 and PAC-S5

Freudlich Isotherm

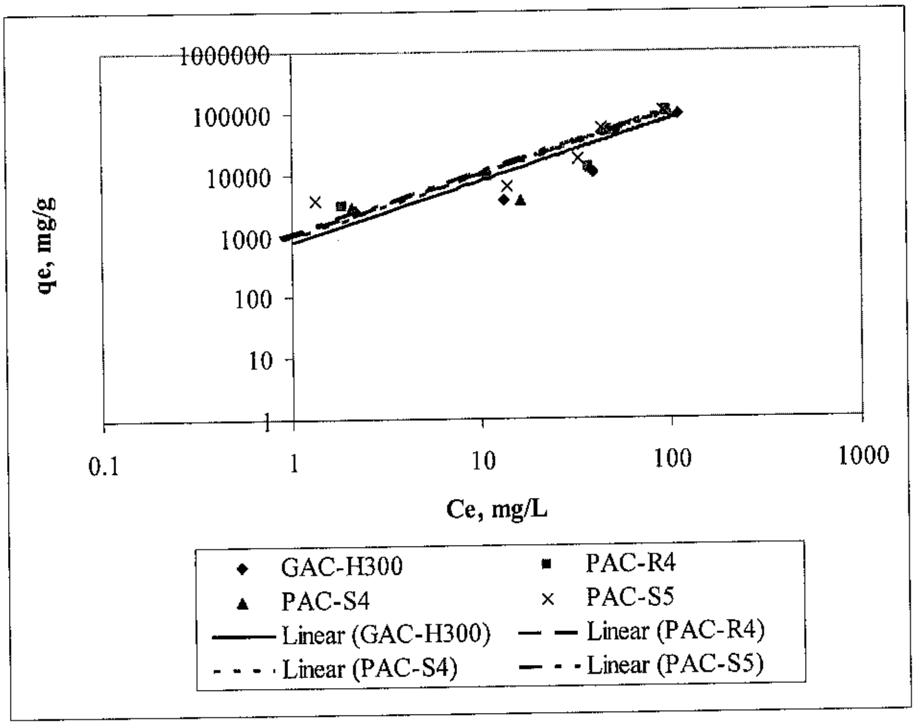


Figure 4.5: Freudlich fit for phenol desorption isotherm for 4 types of activated carbon, GAC-H300, PAC-R4, PAC-S4 and PAC-S5

Langmuir Isotherm

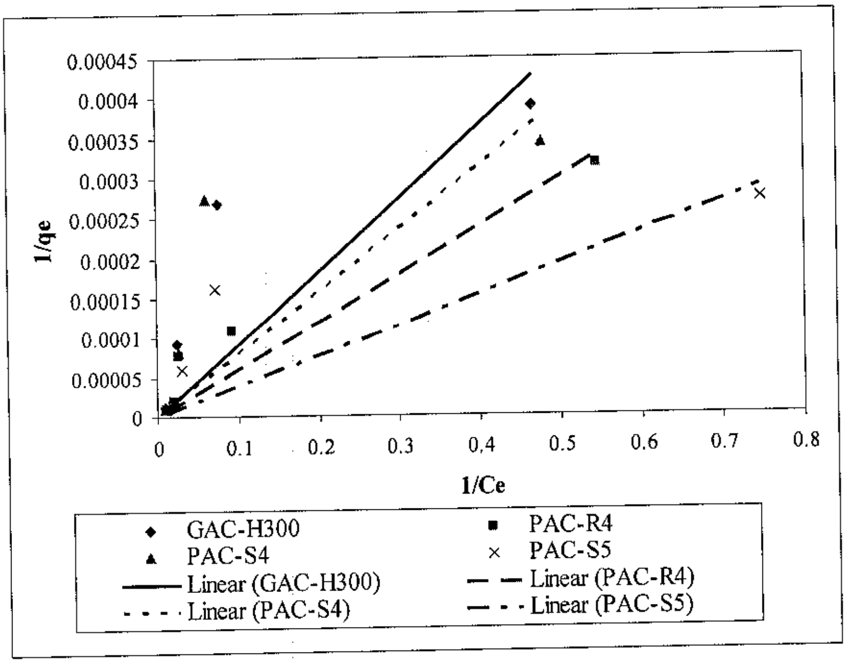


Figure 4.6: Freudlich fit for phenol desorption isotherm for 4 types of activated carbon, GAC-H300, PAC-R4, PAC-S4 and PAC-S5

By using the similar procedures to the one that use for sorption isotherms, the best fit isotherm model for desorption experimental data is determined and the best fit for desorption is Freudlich Isotherm.

Table 4.3: Correlation coefficient, r^2 for Freudlich Isotherm and Langmuir Isotherm for desorption

Activated Carbon	Correlation coefficient, r^2	
	Freudlich Isotherm	**Langmuir Isotherm**
H300	0.9163	0.7334
R4	0.9176	0.9499
S4	0.8993	0.6117
S5	0.9408	0.7711

The equilibrium equation of this model is as follows:

$$q_e = K_F * C_e^{1/n}$$

where q_e = equilibrium adsorbed amount on the adsorbent, C_e = equilibrium concentration, K_F and n = empirical constants depending on the nature of adsorbent and adsorbate.

The constant K_F is an approximate indicator of adsorption capacity, while *1/n* is a function of the strength of adsorption, i.e. mechanism of adsorption. The constants in the model can be obtained by linearization of the above equation:

$$\ln q_e = \ln K_F + \frac{1}{n} \ln C_e$$

The parameters obtained for adsorption of solutes are listed in *Table 4.4.*

Table 4.4: Parameters of the Freudlich equation for desorption of phenol at 20°C on various activated carbons

Activated Carbon	K_F	*1/n*	r^2
H300	-4185.62	0.0128667	0.9163
R4	-4219.53	0.0009791	0.9176
S4	-6953.63	0.0010267	0.8993
S5	-4500.65	0.0009088	0.9408

The fit is quite good under the concentration ranges studied (correlation coefficient, $r^2 > 0.8993$). Based on the *Figure 4.5*, the desorption capacities of the carbons have the following order: S5 > R4 > S4 > H300. This behavior shows the same order as in the typical isotherm (*Figure 4.4*).

4.2 Pores Structures of the Carbon Adsorbers

The pores of adsorbents are classified into three groups, micropores (pore size < 2nm), mesopores (2 – 50nm), and macropores (> 50 nm). In addition, micropores often account for over 95% of the total surface area of common activated carbons (El-Geundi, 1997). The surface characteristics of the carbon adsorbers are shown in *Table 4.5* and T*able 4.6*. Based on these two tables, PAC-S5 has the highest proportions of mesopores fraction of 87.61%, compare to the rest of the activated carbons. And it is observed that powdered activated carbon type of activated carbon has the higher mesopores volumes compare to granular activated carbon.

Table 4.5: Pores characteristic for adsorption list

Carbon types	Adsorption		
	BET surface area , sq.m/g	Pores volume, cc/g	Pores size (diameter), nm
PAC-S4	280.0068	0.307604	43.9424
PAC-R4	260.1233	0.281189	43.2393
PAC-S5	327.8458	0.352173	43.7142
GAC-H300	780.0332	0.557090	28.5675

Table 4.6: Pore specification

Carbon type	Pores	Volume	Total pore volume	Pore size distribution, %
PAC-S4	Macropore	0.015	0.052	5.21
	Mesopore	0.25	0.868	86.81
	Micropore	0.023	0.080	8.00
PAC-R4	Macropore	0.017	0.064	6.42
	Mesopore	0.226	0.853	85.3
	Micropore	0.022	0.083	8.30
PAC-S5	Macropore	0.013	0.039	3.93
	Mesopore	0.290	0.876	87.61
	Micropore	0.028	0.085	8.46
GAC-H300	Macropore	0.0105	0.019	1.93
	Mesopore	0.427	0.784	78.42
	Micropore	0.107	0.197	19.65

4.3 Adsorption Capacities

Figure 4.1 shows the equilibrium adsorption isotherms of phenol onto different carbons in aqueous solutions. In the range of equilibrium concentrations shown in *Figure 4.1*, the adsorption capacities of the carbons have the following order: PAC-S5 > PAC-S4 > GAC-H300 > PAC-R4. However, based on *Table 4.6*, by referring to the mesopores faction the adsorption capacities should have this following order instead: PAC-S5 > PAC-S4 > PAC-R4 > GAC-H300.

Micropores are the major provider of adsorptive sites in aqueous solutions, whereas, in mesopores only weaker adsorption is observed (C.T.Hsieh, H.Teng, 2000). Thus, the adsorption on activated carbon would proceed through a sequence of diffusion steps from the bulk phase into the mesopores and then to the micropores.

A previous study has shown that the surface of the micropores cannot be completely utilized in adsorption and the factional coverage of the micropore surface may depend on the length of the diffusion path. In the process of diffusion in micropores, pore blockage may occur due to the aggregation of adsorbate molecules or it could also be due to the cross-sectional area of some throats in the micropores being too small for the adsorbate to penetrate. Therefore, a longer diffusion path of micropores will result in a greater probability for the pore blockage to occur and, thus a smaller coverage.

With the existence of mesopores in carbon the path length of micropores for the diffusion from mesopores to the carbon interior will be shorter that that when the diffusion comes directly from the bulk phase to the interior without the aid of mesopores. Under this circumstance, mesopores may play a role in not only accelerating the diffusion into micropore, but also in increasing the equilibrium coverage of the micropore surface. The higher phenol capacities of the powered carbons can thus be explained by the fact that the powered carbons contain higher mesopore volumes, thus shortening the diffusion path of micropores for phenol to get access to the carbon interior. Thus, this proven that the result obtain for the order of adsorption capacities should for the following order: PAC-S5 > PAC-S4 > PAC-R4 > GAC-H300. The difference in the result order adsorption capacities with the theoretical may due to other control factors that influence the experiment..

4.4 Desorption Capacities

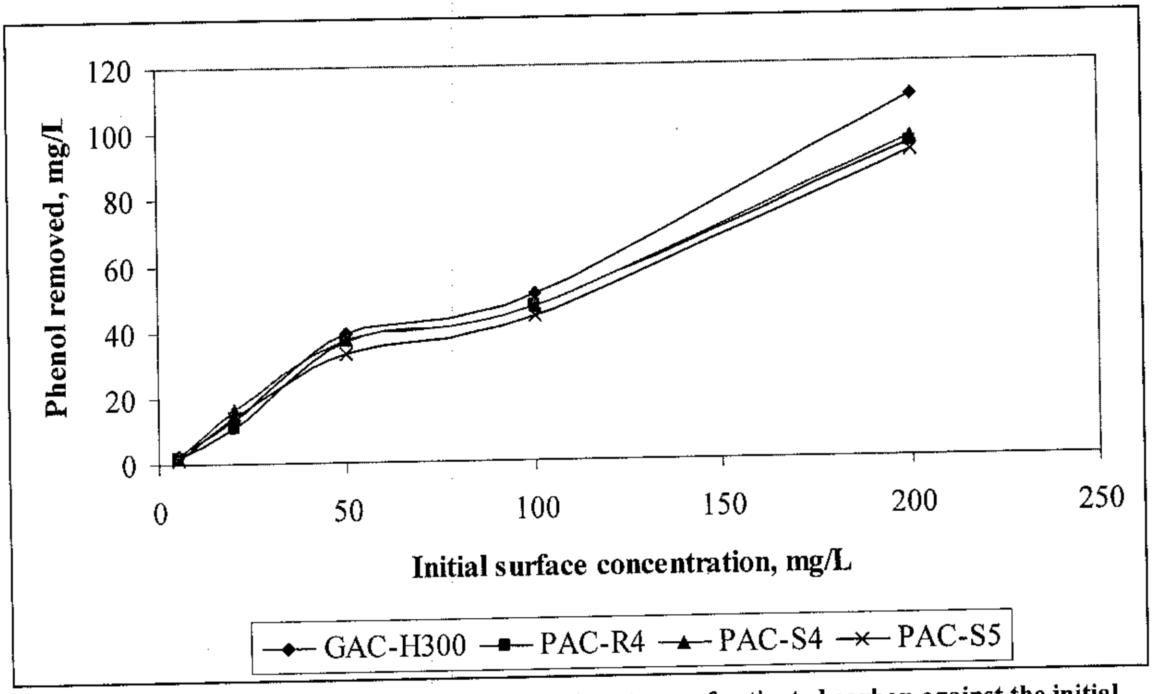


Figure 4.7 : Phenol removed from various types of activated carbon against the initial surface concentration

Base on *Figure 4.7*, it can be observed that as the initial surface concentration increases the phenol removed will also increase. At the initial surface concentration, PAC-S4 has the highest phenol removed while PAC-R4 has the lowest phenol removed. The trend of the removal of phenol from the highest to the lowest as follow: PAC-S4 > PAC-S5 > GAC-H300 > PAC-R4. By referring to the graph, the trend of removal of phenol started to change from initial surface concentration of 50 mg/L. Where from this point to the highest initial surface concentration of 200 mg/L, the highest removal of phenol will be GAC-H300 and PAC-S5 will has the lowest phenol removed. The trend of this change will be as follow: GAC-H300 > PAC-S5 > PAC-S4 > PAC-R4.

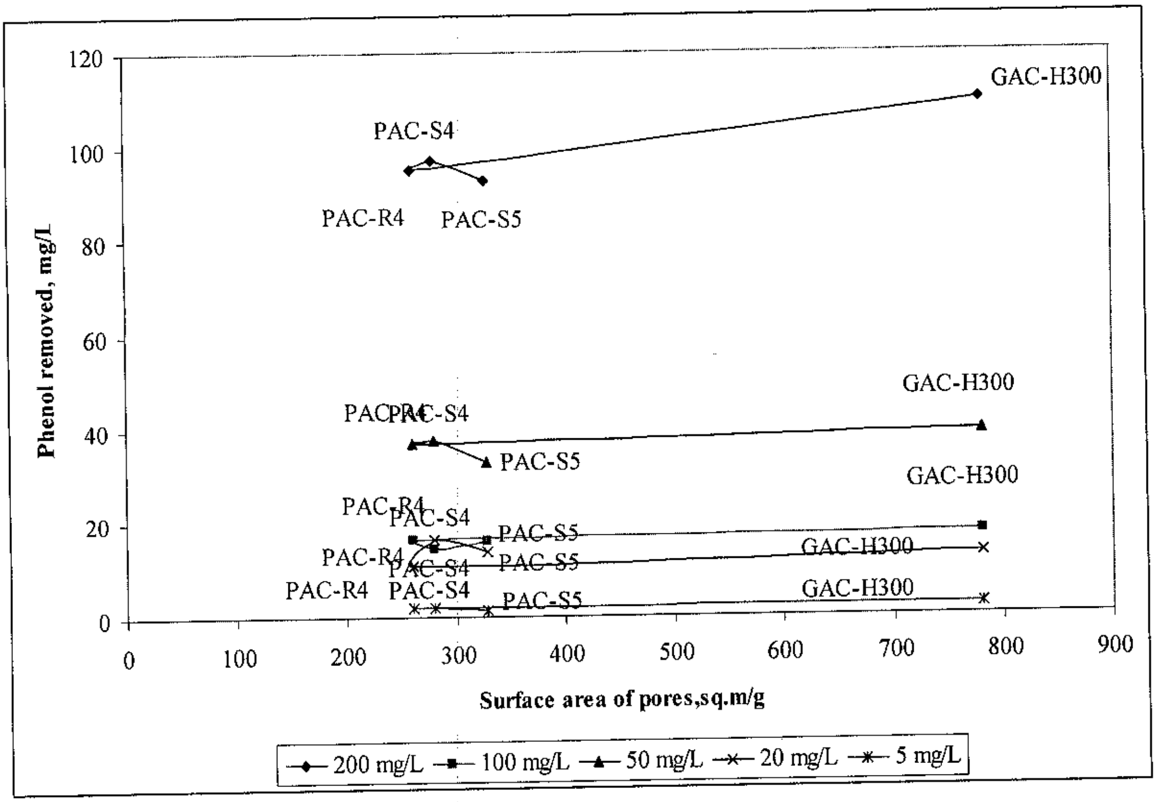


Figure 4.8: Phenol removed from various types of activated carbon against Surface area of pores sq.m/g

Based on *Figure 4.8*, the removal of phenol from the activated carbon increase as the surface area of pores in the activated carbon samples increases. The result obtain has the similar pattern as in *Figure 4.7*. From here, it can also be justified physically that granular activated carbon has the higher removal of phenol compare to the powdered activated carbon. This is due to larger surface area of pores for granular activated carbon compare to powered activated carbon.

In order to justify the behavior and the changes, the functional group (phenol) attraction to the activated carbon need to be studied too. Where, the factor of surface charge need to be determined. However, this factor will not be discussed in this study. Other than that, other reason that need to be consider is chemical reaction might had taken place between the phenol and the activated carbon itself. Therefore, this will lessen the phenol that need to be removed.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

Overall the study on the factor that influence adsorption and desorption of phenol unto activated carbons on types of activated carbon used was successfully completed within the period given. All the mentioned objectives had been achieved and the result is reported in this report. Experimental works had been carried out successful in order to obtain related result to the study of adsorption and desorption. Results were then plotted in few types of isotherms. The best fit isotherm for adsorption and desorption were determine by comparing the correlation coefficient, r^2, for each isotherm. The best fit isotherm for adsorption isotherm is Langmuir isotherm and the best fit for desorption isotherm is Freudlich isotherm. Other than that, it can be conclude that the types of activated carbon do matter in the study. Where, PAC has higher adsorption capacities compare to GAC. This is because PAC has high mesopores volume. The theoretical result should be as follow: PAC-S5 > PAC-S4 > PAC-R4 > GAC-H300. However, the experiment results do no tally with it. This may be due to other control factor that influence adsorption, such as polarity, surface charge and pH. For desorption, GAC has higher desorption capacities compare to PAC. This can be explained by the large surface area of pores in GAC. It is recommended that a further study on the functional group attraction to the activated carbon in desorption to be conducted in the future. This in order to obtain a better results and explanation compare to the one conducted in this study.

5.2 RECOMMENDATIONS

1. For future study of desorption, it is recommended to study on the attraction of functional group with the activated carbon. This in order to know how strong is the attraction and from this a method to weaken the attraction can be obtained. This will increase the amount of adsorbents removed from the activated carbon. This study is also important in order to increase the efficiency in regeneration of activated carbon.

2. This study can be enhanced by using more types and number of activated carbons. This is because it is not sufficient to have only four samples of activated carbons, and only two types to be compared with. Moreover, various type of activated carbon can be used to analyse the adsorption and desorption behaviour at different concentration extreme and temperature. This will provide a wider range of result with clearer justification of choosing the preferred activated carbon.

3. The adsoption and desorption model in this project can be incorporated in mathemathical programming approach such as MATLAB and MS Excel spreadsheet in order to represent the data and results in graphical form for better analysis. These programs can store large amount of data hence enable us to compare the adsoption and desorption characteristics with previous samples or models.

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APPENDICES

Appendix 1: Standard Adsorption Curve

Appendix 2: Adsorption Experiment Results

Appendix 3: Desorption Experiment Results

Appendix 1: Standard Adsorption Curve

Table A.1: Result for standard solutions

Concentration, mg/l	Absorbance			
	1	2	3	Average
200	2.757	2.6929	2.71	2.719967
100	1.6405	1.65	1.6667	1.6524
50	0.7864	0.7916	0.7765	0.784833
30	0.4412	0.4408	0.4408	0.440933
20	0.3692	0.349	0.3414	0.3532
5	0.2231	0.2238	0.2221	0.223
0	0	0	0	0

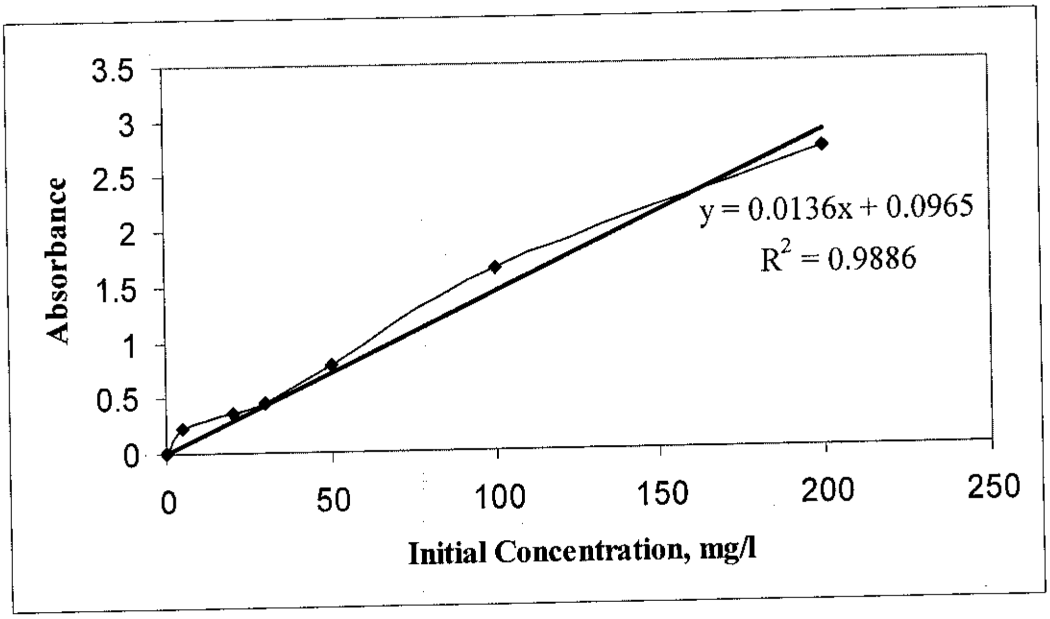

Figure A.1: Standard Curve

Appendix 2: Adsorption Experiment Results

Table A.2: Concentration 200mg/l

Activated Carbon	Absorbance				Concentration, mg/l	q_e
	1	2	3	Average		
H300	1.174	1.1252	1.1298	1.143	79.18018	120819.8
R4	1.3394	1.305	1.3046	1.316333	91.18768	108812.3
S4	1.083	1.0828	1.0835	1.0831	75.03067	124969.3
S5	0.8651	0.8652	0.865	0.8651	59.92894	140071.1

Table A.3: Concentration 100mg/l

Activated Carbon	Absorbance				Concentration, mg/l	q_e
	1	2	3	Average		
H300	0.2723	0.2276	0.2659	0.255267	17.68334	82316.66
R4	0.245	0.2201	0.2501	0.2384	16.51492	83485.08
S4	0.2127	0.2055	0.2064	0.2082	14.42285	85577.15
S5	0.2196	0.2365	0.2384	0.2315	16.03693	83963.07

Table A.4: Concentration 50mg/l

Activated Carbon	Absorbance				Concentration, mg/l	q_e
	1	2	3	Average		
H300	0.1021	0.115	0.1838	0.133633	9.257316	40742.68
R4	0.091	0.1142	0.089	0.098067	6.79347	43206.53
S4	0.0675	0.105	0.0844	0.085633	5.932164	44067.84
S5	0.0998	0.0828	0.0945	0.092367	6.398608	43601.39

Table A.5 : Concentration 20mg/l

Activated Carbon	Absorbance				Concentration, mg/l	q_e
	1	2	3	Average		
H300	0.0866	0.0795	0.0799	0.082	5.680468	14319.53
R4	0.0237	0.0225	0.0269	0.024367	1.687976	18312.02
S4	0.0485	0.0297	0.0164	0.031533	2.18444	17815.56
S5	0.0216	0.0395	0.0218	0.027633	1.914272	18085.73

Table A.6: Concentration 5mg/l

Activated Carbon	Absorbance				Concentration, mg/l	q_e
	1	2	3	Average		
H300	0.0255	0.0264	0.0267	0.0262	1.814979	3185.021
R4	0.0223	0.0226	0.0222	0.022367	1.549428	3450.572
S4	0.0295	0.0303	0.0279	0.029233	2.02511	2974.89
S5	0.0312	0.0368	0.0235	0.0305	2.112857	2887.143

Table A.7: Tabulation of results

Conc. mg/l	H300		R4		S4		S5	
	Ce	qe	Ce	qe	Ce	qe	Ce	qe
200	79.18	120819.8	91.19	108812.3	75.03	124969.3	59.93	140071.1
100	17.68	82316.66	16.51	83485.08	14.42	85577.15	16.04	83963.07
50	9.26	40742.68	6.79	43206.53	5.93	44067.84	6.4	43601.39
20	5.68	14319.53	4.35	18312.02	4.00	17815.56	5.05	18085.73
5	1.81	3185.02	1.55	3450.57	2.03	2974.89	2.11	2887.14
0	0	0	0	0	0	0	0	0

Appendix 3: Desorption Experiment Results

Table A.8: Concentration 200mg/l

Activated Carbon	Absorbance				Concentration, mg/l	q_e
	1	2	3	Average		
H300	1.5324	1.5642	1.654	1.583533	109.6977	90302.31
R4	1.3599	1.3985	1.3658	1.374733	95.23328	104766.7
S4	1.3956	1.4265	1.3857	1.4026	97.16371	102836.3
S5	1.3406	1.349	1.3399	1.343167	93.04653	106953.5

Table A.9: Concentration 100mg/l

Activated Carbon	Absorbance				Concentration, mg/l	q_e
	1	2	3	Average		
H300	0.2723	0.2276	0.2659	0.255267	17.68334	82316.66
R4	0.245	0.2201	0.2501	0.2384	16.51492	83485.08
S4	0.2127	0.2055	0.2064	0.2082	14.42285	85577.15
S5	0.2196	0.2365	0.2384	0.2315	16.03693	83963.07

Table A.10: Concentration 50mg/l

Activated Carbon	Absorbance				Concentration, mg/l	q_e
	1	2	3	Average		
H300	0.556	0.579	0.568	0.567667	39.32454	10675.46
R4	0.5314	0.5602	0.5104	0.534	36.99232	13007.68
S4	0.5485	0.5506	0.5301	0.543067	37.6204	12379.6
S5	0.4589	0.47601	0.4901	0.475003	32.90538	17094.62

Table A.11: Concentration 20mg/l

Activated Carbon	Absorbance				Concentration, mg/l	q_e
	1	2	3	Average		
H300	0.1917	0.1845	0.1987	0.191633	13.27521	6724.792
R4	0.1557	0.1512	0.1605	0.1558	10.79289	9207.111
S4	0.23075	0.2418	0.2354	0.235983	16.34751	3652.491
S5	0.1999	0.1995	0.1993	0.199567	13.82478	6175.219

Table A.12: Concentration 5mg/l

Activated Carbon	Absorbance				Concentration, mg/l	q_e
	1	2	3	Average		
H300	0.0347	0.0354	0.0353	0.035133	2.433827	2566.173
R4	0.0282	0.0266	0.0246	0.026467	1.833452	3166.548
S4	0.0305	0.0297	0.0301	0.0301	2.085147	2914.853
S5	0.0192	0.0189	0.0199	0.019333	1.339297	3660.703

Table A.11: Tabulation of results

Conc. mg/l	H300		R4		S4		S5	
	Ce	qe	Ce	qe	Ce	qe	Ce	qe
200	109.7	90302.31	95.23	104766.7	97.16	102836.3	93.05	106953.5
100	50.89	49106.7	47.18	52819.79	47.29	52708.95	44.1	55904.79
50	39.32	10675.46	36.99	13007.68	37.62	12379.6	32.91	17094.62
20	13.28	3724.79	10.79	9207.11	16.35	3652.49	13.82	6175.22
5	2.14	2566.17	1.83	3166.55	2.09	2914.85	1.34	3660.7
0	0	0	0	0	0	0	0	0