References

[1] Edward N. Ruddy and Leigh Ann Carroll. Select the best voc control strategy. *Chem. Eng. Progres*, 28, 1993.

[2] H. Bohn. Consider biofiltration for decontaminating gases. *Chem. Eng. Progress*, 88(4):34–40, 1992.

[3] M. Thorpe. Plasma energy: The ultimate in heat transfer. *Chem. Eng. Progress*, 85(7):43, 1989.

[4] G. Ondrey and K. Fouhy. Plasma arcs sputter new waste treatment. *Chem. Eng.*, 98(12):32.

[5] A.A. Isirikyan and A.V. Kisele. Adsorption isotherms of nitrogen benzene and n-hexane and the heats of adsorption of benzene and n-hexane on graphitized carbon blacks iii. the thermodynamic characteristics of adsorption equilibria. *J. Phy. Chem.*, 66:210–21, 1962.

[6] A. Swiatkowski. Description of an active carbon micropore size distribution based on the horvath-kawazoe equation adapted benzene adsorption isotherm. *Adsorption Science and Technolog*, 14(1):59–67, 1996.

[7] Kazuyuki Chihara, Motoyuki Suzuki, and Kunitaro Kawazoe. Adsorption rate on molecular sieving carbon by chromatographic. *AIChE J.*, 24(2):237–246, 1978.

[8] Kunitaro Kawazoe, Motoyuki Suzuki, and Kazuyuki Chihara. Chromatographic study of diffusion in molecular sieving carbon. *J. Chem. Eng. of Japan*, 7(3):151–157, 1974.

[9] Jeong-Ho Yun and Dae-Ki Choi. Adsorption isotherm of benzene and methyl-benzene vapors on activated carbon. *J. Chem. Eng. Data*, 42:894–896, 1997.

[10] K.E. Noll. Adsorption of organic vapors on carbon and resin. *J. of Envi. Eng.*, 111(4):847–500, 1985.

[11] Raul Chao and H.E. Hoelscher. Simutaneous axial dispersion and adsorption in a packed bed. *AIChE J.*, 12(2):271–278, 1968.

[12] Neung-Wan Han, Jayendra Bhakta, and R.G. Carbonell. Longitudinal and lateral dispersion in packed beds: Effect of column length and particle size distribution. *AIChE J.*, 31(2):277–288, 1985.

[13] S.M. Ashraf. Determination of binary gas-phase diffusion coefficients using chromatography. *J. Chem. Eng. Data*, 31:100–102, 1986.

[14] Motoyuki Suzuki and J.M. Smith. Axial dispersion in beds of small particles. *Chem. Eng. J.*, 3:256–264, 1972.

[15] P. Scheider and J. Smith. Adsorption rate constants from chromatography. *AIChE J.*, 14:762–771, September 1968.

[16] P. Scheider and J. Smith. Chromatographic study of surface diffusion. *AIChE J.*, 14:886–895, November 1968.

[17] H. W. Haynes and P. N. Sarma. Model for the application of gas chromatography to measurements of diffusion in bidiperse structured catalysts. *AIChE J.*, 19:1043–1046, 1973.

[18] J.R. Hofton and R.P. Danner. Chromatographic study of alkanes in silicallite. *AIChE J.*, 1993.

[19] C.L. Mantel. *Adsorption, 2nd ed.* McGraw-Hill book company Inc., 1951.

[20] Douglas M. Ruthven. *Principle of Adsorption and Adsorption Process.* John Wiley & Sons, 1984.

[21] Ralph T. Yang. *Gas Separation by Adsorption Processes*. Butterworth Pubishers, 1987.

[22] Smisek, Milan, Cerny, and Slavy. *Active carbon manufacture property and application*. Amsterdam : Elsevier Publishing Company, 1965.

[23] J.H. You, H.L. Chiang, and P.C. Chiang. Comparison of adsorption characteristics for vocs on activated carbon and oxidized activated carbon. *Envi. Prog.*, 13(1):31–36, 1994.

[24] Kenneth E. Noll, Vassilios Gounaris, and Wain-Sun Hou. *Adsorption Technology for Air and Water Pollution Control*. Lewis Publishers,Inc, 1992.

[25] Rees, J. Hamson, and Bruckner P. *Sorption of single gases and their binary mixtures in zeolite*. Netherland: Kluwer Academic, 1992.

[26] H. Grajek, S. Neffe, and Z. Witkiewicz. Chromatographic determination of the physico-chemical parameters of adsorption on activated carbon fibres. *J. Chromatography*, W600:67, 1992.

[27] Albert Yehaskel. *Activated Carbon Manufacture and Regeneration*. Noyes DATA Corporation, 1978.

[28] Laila B. Khalil and Badie S. Girgis. Adsorption of p-nitrophenal on activated carbon prepared from phosphoric acid-treated apricot stone shells. *Adsorption Science and Technology*, 12(1):79, 1995.

[29] Pongsathorn Kaokachathorn. Activated from corncob. Master's thesis, Chulalongkorn University, 1995.

[30] ASTM Committee on Standards. *American Standard of Testing Material, Standard Test Method for Determination of Moisture of Activated carbon ASTM D4067-94*. National Institute of Standards and Technology, 1991.

[31] ASTM Committee on Standards. *American Standard of Testing Material, Standard Test Method for Determination of Iodine Number of Activated carbon ASTM D4067-94*. National Institute of Standards and Technology, 1994.

[32] Purida Pimanmad and Vitchaya Witchayaphai boonnak. Activated carbon from corncob. Technical report, Department of Chemical Engineering, Faculty of Engineer, Chulalongkorn University, 1997.

[33] H. Grajek, Z. Witkiewicsz, and H. Jankowska. Application of kovats retention indices for investigation of adsorption properties of activated carbons. *J. of Chromatography*, 782:87–94, 1997.

Appendix A

Examples of calculation

A.1 Calculation of concentration

$$From \quad logP^{vap} \quad = \quad A - \frac{B}{C+t} \qquad (A.1)$$

where $\quad$ P^{vap} $\quad = \quad$ vapor pressure in mm. Hg

$\qquad\qquad$ t $\qquad = \quad$ temperature in ° C

Substitued toluene data in Equation A.1 , we obtain

$$\log P^{vap} \quad = \quad 6.95464 - \frac{1344.800}{219.482 + 30}$$

$$= \quad 1.5643$$

$$P^{vap} \quad = \quad 10^{1.5643} \text{ mm. Hg}$$

$$= \quad 36.6691 \text{ mm. Hg}$$

$$\% \text{ toluene} \quad = \quad \frac{partial\ pressure\ of \quad toluene}{absolute\ pressure} \times 100$$

$$= \quad \frac{36.6691}{760} \times 100$$

$$= \quad 4.82$$

A.2 Calculation of iodine number of carbon adsorbents

$$\frac{mg}{g} = x/m \times D \qquad (A.2)$$

$$x/m = \frac{A-(DF)(B)(S)}{M}$$

$$C = \frac{N_1 \times S}{F}$$

$$DF = \frac{I+H}{F}$$

where

x/m	=	iodine absorbed per gram of carbon, mg/g
S	=	sodium thiosulfate, ml
M	=	carbon used, g
N_1	=	sodium thiosulfate, N
N_2	=	iodine, N
A	=	$N_2 \times 12693.0$
B	=	$N_1 \times 126.93$
C	=	residual filtrate, N
I	=	iodine, ml
H	=	5% hydrochloric acid used, ml
F	=	filtrate, ml
D	=	correction factor
DF	=	dilution factor

For carbon adsorbent which activated with $ZnCl_2$

Let	N_1	=	0.0996 N
	N_2	=	0.1002 N
	A	=	1271.8386
	B	=	12.6422
	DF	=	(50+10)/25
		=	2.4
	C	=	(0.0996 x6.5 /25)
		=	0.0259
	D	=	0.96

Substitued these value in Equation A.2 , we obtain

$$\frac{mg}{g} = \frac{1271.8386-(2.4\times12.6422\times6.5)}{0.8308} \times 0.96$$

$$= 1241.74$$

A.3 Calculation of moisture content on carbon adsorbents

From

$$\%moisture = \frac{loss \quad weight \times 100}{original \; weight} \qquad (A.3)$$

For carbon adsorbent which activate with $ZnCl_2$

Let   loss weight   =   1.3459 g

original weight   =   1.3259 g

Substitued these value in Equation A.3 , we obtain

$$\% \text{ moisture} = \frac{1.3459 - 1.3259}{1.3459} \times 100$$

$$= 1.49$$

A.4   Calculation of bed porosity and particle density

From Blake-Kozeny's equation :

$$log\frac{\Delta P \rho D_p^2}{\mu L} = -logRe + log\left(\frac{150(1-\varepsilon)^2}{\varepsilon^3}\right)$$

For carbon adsorbent activated with 50% H_3PO_4

The graph between $log \frac{\Delta P \rho D_p^2}{\mu L}$ and log Re from data, we obtain

intercept: $log\frac{150(1-\varepsilon)^2}{\varepsilon^3}$ =   3.1934

$\frac{150(1-\varepsilon)^2}{\varepsilon^3}$ = $10^{3.1934}$

$\frac{(1-\varepsilon)^2}{\varepsilon^3}$ =   10.4066

$10.4066\varepsilon^3 - \varepsilon^2 + 2\varepsilon - 1$ =   0

ε =   0.3453

$1 - \varepsilon$ = $\frac{V_{solid}}{V_{column}}$

     = $\frac{mass/density}{3.14 \times r^2 \times 12.3}$

1-0.3453   = $\frac{0.7342/density}{3.14 \times 0.2286^2 \times 12.3}$
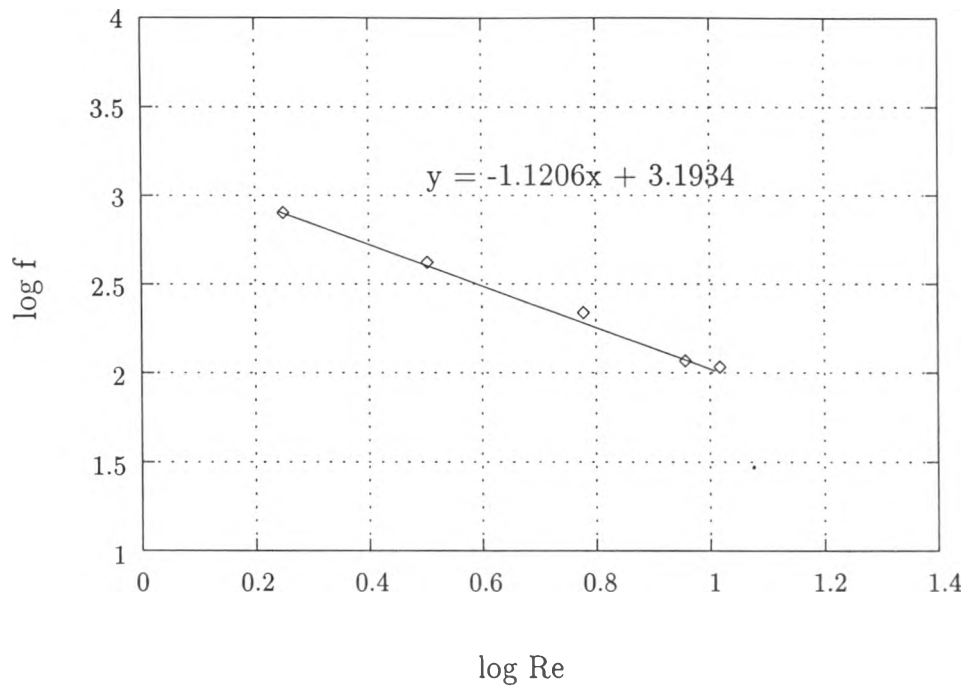
then   density   =   0.555 g / cm^3

Figure A.1: The plot of friction factor versus Reynold number for flow through packed bed according to Blake-Kozeny equation on carbon adsorbent 50% H_3PO_4

A.5 Calculation of Adsorption Equilibrium Constants

The adsorption equilibrium constants is calculated from Equation 2.14 by the plot of $\frac{L}{v}$ versus t_r such as shown in Figure A.2

$$ t_r \quad = \frac{L}{v}\left[1 + \left(\frac{1-\varepsilon}{\varepsilon}\right)K\right] $$

The slope of the stright line is equal to $1+\left(\frac{1-\varepsilon}{\varepsilon}\right)$ K. The bed porosity is 0.4998 Then,

$$ K \qquad = \quad (slope - 1)\frac{\varepsilon}{1-\varepsilon} $$

$$ = \quad (37931\text{-}1)\,\frac{0.4998}{1-0.4998} $$

$$ = \quad 6614.51 $$
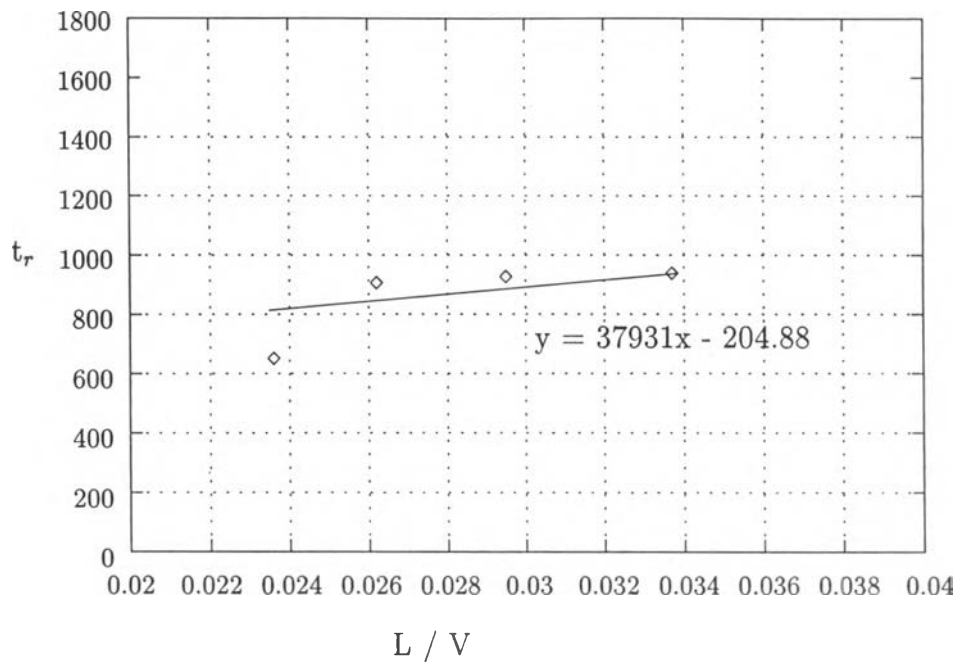
Figure A.2: Adsorption equilibrium constants on carbon adsorbent 50% H_3PO_4 at temperature 190°C

A.6 Calculation of Heat of Adsorption

From vant't Hoff equation

$$\frac{dlnK}{dt} = \frac{\Delta H}{RT^2} \tag{A.4}$$

$$lnK = \ln K_0 - \frac{\Delta H}{RT} \tag{A.5}$$

Then, we plot graph between lnK and 1000/T as illustrated in Figure A.3.

The slope of graph equal to $\frac{-\Delta H}{R}$

From the figure A.3, we can calculate the heat of adsorption

$$
\begin{aligned}
\text{Heat of adsorption} \quad &= \quad \text{slope} \times R \\
&= \quad 6.673 \times 8.314 \text{ J/mol} \\
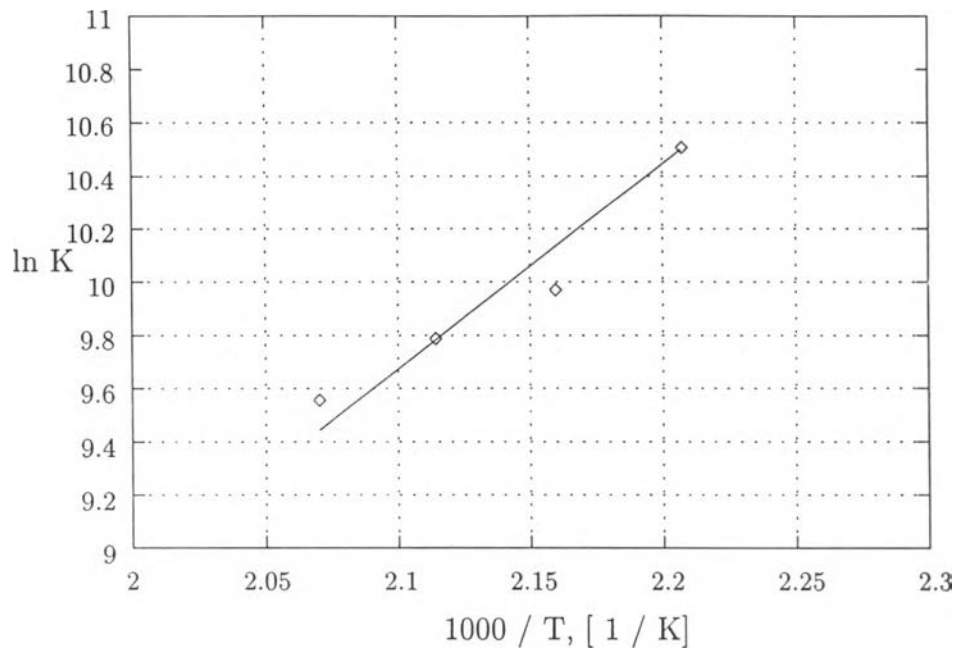&= \quad 55.48 \text{ kJ/mol}
\end{aligned}
$$

Figure A.3: The adsorption equilibrium constants of toluene on carbon adsorbent ZnCl$_2$ at various temperature

A.7   Calculation axial dispersion coefficients and mass transfer coefficients

From equation;

$$\frac{\sigma^2}{2t_r^2} = \frac{D_L}{vL} + \frac{v}{L}\frac{\varepsilon}{1-\varepsilon}\frac{1}{kK}\left[1 + \frac{\varepsilon}{(1-\varepsilon)K}\right]^{-2}$$

rearrangement equation, we obtain

$$\frac{\sigma^2}{2t_r^2}\frac{L}{v} = \frac{D_L}{v^2} + \frac{\varepsilon}{1-\varepsilon}\frac{1}{kK}\left[1 + \frac{\varepsilon}{(1-\varepsilon)K}\right]^{-2}$$

The plot of $\frac{\sigma^2}{2t_r^2}\frac{L}{v}$ versus $\frac{D_L}{v^2}$ should be linear as shown in Figure A.4. The overall mass transfer coeffcient is calculated from the intercept of the line and the slope is corresponding to axial dispersion coefficient

A.7.1   mass transfer coefficient

$$intercept = \left(\frac{\varepsilon}{1-\varepsilon}\right)\frac{1}{kK}\left[1 + \frac{\varepsilon}{(1-\varepsilon)K}\right]^{-2}$$
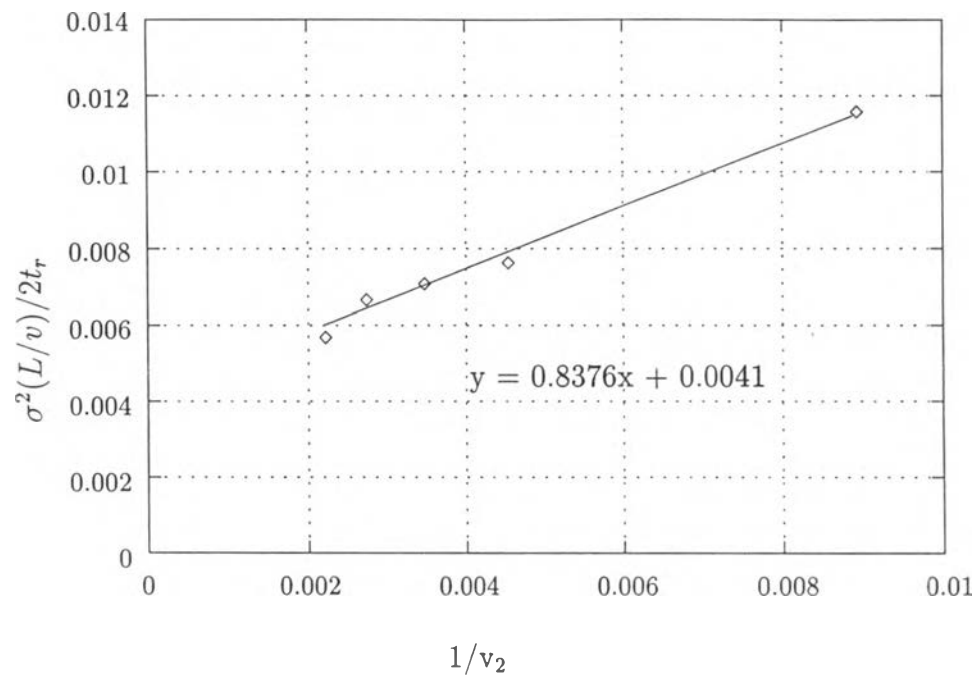
Figure A.4: Overall mass transfer coefficients of toluene on carbon adsorbent which activated with 50% H_3PO_4 at temperature 190°C

Therefore, the overall mass transfer coefficient of toluene on carbon adsorbent activated with 50% H_3PO_4 at 190°C is

$$0.0041 = \left(\frac{\varepsilon}{1-\varepsilon}\right)\frac{1}{kK}\left[1 + \frac{\varepsilon}{(1-\varepsilon)K}\right]^{-2}$$

$$k = \frac{0.4998}{1-0.4998}\frac{1}{6614.51\times0.0041}\left[1 + \frac{0.4998}{(1-0.4998)\times6614.51}\right]^{-2}$$

$$= 0.0279 \ 1/\text{sec}$$

A.7.2   axial dispersion coefficient

$$slope = D_L$$

Therefore, the axial dispersion coefficient of toluene on carbon adsorbent which activated with 50% H_3PO_4 at 190°C is
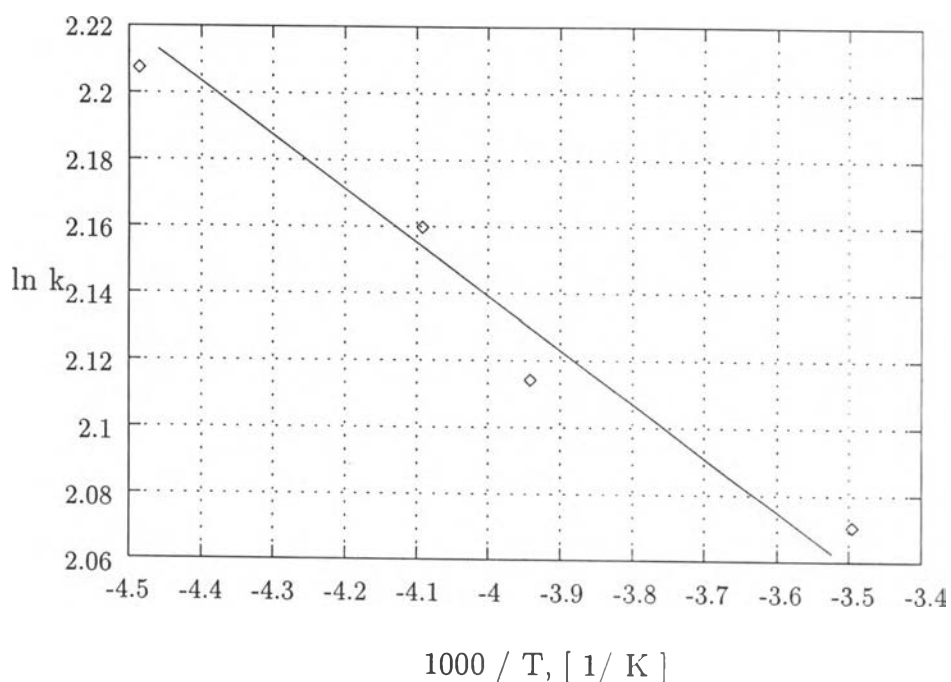
Figure A.5: Activation energy of toluene on carbon adsorbent which activated with $ZnCl_2$

$$D_L \quad = \quad \text{slope}$$
$$\quad = \quad 0.8376 \text{ cm}^2/\text{sec}$$

A.8 Calculation activation energy

$$k = k_0 exp\left(-\frac{Ea}{RT}\right) \qquad (A.6)$$

$$lnk = lnk_0 - \frac{Ea}{RT} \qquad (A.7)$$

The activation energy is calculated from the slope of plot of lnk versus 1000/T as shown in Figure A.5.

Therefore, the activation energy of toluene on carbon adsorbent which activated with $ZnCl_2$ is

$$\text{slope} \quad = \quad -\frac{E_a}{R}$$

$$-6.8248 \quad = \quad -\frac{E_a}{8.314}$$

$$E_a \quad = \quad 56.74 \text{ kJ/mol}$$

Appendix B

Standard Terminology Relating to Activated Carbon

- activated carbon-a family of carboneceous substances manufactured by process that develop adsorptive properties.

- activation - any process whereby a substance is treated to develop adsorptive properties.

- adsorbate - any substance that is or can be adsorbed.

- adsorbent - any solid having the ability to concentrate significant quantities of other substances on its surface.

- adsorption - a process in which fluid molecules are concentrated on a surface by chemical or physical forces, or both.

- degassing - removal of gases.

- density, particle - the mass under specified conditions of a unit volume of a solid sorbent including its pore volume but excluding inter-particle voids.

- heat of adsorption - the heat evolved during adsorption.

- isotherm - a plot of quantity adsorbed per unit of adsorbent against equilibrium concentration, or pressure, when temperature is held constant.

- mean particle diameter - the weighted average particle size, in millimeters, of a granular adsorbent computed by multiplying the percent retained in a size fraction by the respective mean sieve openings, summing these values and dividing by 100.

- moisture content - the water content of a substance as measured under specified conditions.

- physical adsorption (van der Waals adsorption) - the binding of an adsorbed to the surface of a solid by forces whose energy levels approximate those of condensation.

- pore diameter - the diameter of a pore in a model in which the pores in a sorbent are assumed to be cylindrical in shape and which is calculated from data obtained by a specified procedure.

- pores - the complex network of channels in the interior of a particle of a sorbent.

- pore volume - volume of the pores in a unit weight of a sorbent.

- surface area (B.E.T.) - the total surface area of a solid calculated by the B.E.T. (Brunauer, Emmett, Teller) equation, from nitrogen adsorption or desorption data obtained under specified conditions.

- surface oxides - oxygen containing compounds and complexes formed at the surface of an adsorbent.

Appendix C

Standard Test Method for Determination of Iodine Number of Carbon Adsorbent

This test method covers the determination of the relative activation level of unused or reactivated carbons by adsorption of iodine from aqueous solution. The amount of iodine absorbed (in milligrams) by 1 g of carbon using test conditions listed herein is called the iodine number A.2.

C.1 Significance and Use

The iodine number is a relative indicator of porosity in an activated carbon. It does not necessarily povide a measure of the carbon's ability to adsorb other species. Iodine number may be used as an approximation of surface area for some types of activated carbons. However, it must be realized that any relationship between surface area and iodine number cannot be generalized. It varies with changes in carbon raw material, processing conditions, and pore volume distribution.

C.2 Apparatus

1. Analytical Balance (4 position)

2. Buret, 10-mL capacity or 5-mL precision buret.

3. Flasks, Erlenmeyer 250-mL capacity with ground glass stoppers.

4. Flask, Erlenmeyer wide-mounted, 250-mL capacity.

5. Beakers, assorted sizes.

6. Bottles, amber, for storage of iodine and thiosulfate solutions.

7. Funnels, 100-mm top inside diameter.

8. Filter Paper, 18.5-cm prefold paper, Whatman No. 2V or equilivalent.

9. Pipets, volumetric type, 5.0, 10.0, 25.0, 50.0, and 100.0 mL capacity.

10. Volumetric Flask, 1L.

11. Gratuated Cylinders, 100 mL and 500 mL.

C.3   Reagents

1. Purity of Reagents- Reagent grade chemicals shall be used in all tests. Unless otherwise indicated, it is intended that all reagents shall conform to the specifications of the Committee on Analytical Society, where such specifications are available. Other grades may be used, provided it is first ascertained that the reagent is of suficietly high purity to permit its use without lossening the accuracy of the determination.

2. Purity of Water-References to water shall be understood to mean reagent water.

3. Hydrochloric Acid, concentrated.

4. Sodium Thiosulfate, $(Na_2S_2O_3.5\ H_2O)$.

5. Iodine.

6. Potassium Iodide.

7. Potassium Iodate, primary standard.

8. Starch, soluble potato or arrowroot.

9. Sodium Carbonate.

C.4   Preparation of Solutions

1. Hydrochloric Acid Solution (5% by weight)

   Add 70 mL of concentrated hydrochloric acid to 550 mL of distilled water and mix well. A graduated cylinder may be used for measurement of volume.

2. Sodium Thiosulfate (0.100 N)

   Dissolve 24.820 g of sodium thiosulfate in approximately 75 ml$\pm$25 mL of freshly boiled distilled water. Add 0.10$\pm$0.01 g of sodium carbonate to minimize bacterial decomposition of the thiosulfate solution. Quantitatively transfer the mixture to a 1-L volumetric flask and dilute to the mark. Allow the solution to stand at least 4 days before standardizing. The solution should be stored in an amber bottle.

3. Standard Iodine Solution (0.100$\pm$0.001 N)

   Weigh 12.700 g of iodine and 19.100 g of potassium iodide (KI) into a beaker. Mix the dry iodine and potassium iodide. Add 2 to 5 mL of water to the beaker and stir well. Continue addig small increments of water (approximately 5 mL each) while stirring until the total volume is 50 to 60 mL. Allow the solution to stand a minimum of 4 hrs. to ensure that all crystals are thoroughly dissolved. Occasional stirring during this 4-hrs. period will aid in the dissolution. Quantitatively transfer to a 1-L volumetric flask and fill to the mark with distilled water. It is important that the standard iodine solution has an iodide-to-iodine weight ratio of 1.5 to 1. Store the solution in an amber bottle.

4. Potasium Iodate Solution (0.1000 N)

   Dry 4 or more grams of primary standard grade potassium iodate (KIO$_3$) at 110 $\pm$5°C for 2 hrs. and cool to room emperature in a desiccator. Dissolve

3.5667±0.1 mg of the dry potassium iodate in about 100 mL of distilled water. Quantitatively transfer to a 1-L volumetric flask and fill to the mark with distilled water. Mix thoroughly and store in a glass-stoppered bottle.

5. Starch Solution

Mix 1.0±0.5 g of starch with 5 to 10 mL of water while stirring to the starch paste. Add an additional 25±5 mL of water while stirring to starch paste Pour the mixture, while stirring, into 1 L of boiling water and boil for 4 to 5 min. This solution should be made fresh daily.

C.5   Standardization of Solution

1. Standardization of 0.100±0.001 N Iodine Solution

Pipet 25.0 mL of iodine solution into Wide-mounted Erlenmeyer flask. Titrate with standardized sodium thiosulfate until the iodine solution is a light yellow color. Add a few drops of starch indicator and continue titraton dropwise until one drop produces a colorless soluton. Determine the iodine solution normality as follows:

$$N_1 = (S \times N_2)/I$$

where:

N_1	=	sodium thiosulfate, N
N_2	=	iodine, N
I	=	iodine, mL
S	=	sodiium thiosulfate, mL

2. Standardization of 0.100 N Sodium Thiosulfate

Pipet 25.0 mL of potassium iodate (KIO_3) solution into a 250-mL titration (or wide-mounthed Erlenmeyer) flask. Add 2.00± 0.01 g of potassium iodide (KI) to the flask and shake the flask to dissolve the potassium iodide crystals. Pipet 5.0 mL of concentrated hydrochloric acid into the flask. Titrate the free iodine with sodium thiosulfate solution until a light yellow color is observed

in the flask. Add a few drops of starch indicator and continue the titration dropwise until one drop produces a colorless solution. Determine sodium thiosulfate normality as follows:

$$N_2 = \frac{P \times R}{S}$$

where:

N_2	=	iodine, N
P	=	potassium iodate, mL
R	=	potassium iodate, N
S	=	sodium thiosulfate, mL

C.6 Procedure

1. Grind sample of carbon until 95 wt% or more will pass through a 100 mesh screen

2. Dry the ground carbon at 110°C for 3 hours and then cooled in desicator

3. Transfer weighed dry carbon in 250 ml Erlenmeyer flask equipped with stopper

4. Pipet 10.0 ml of 5 wt% HCl solution into flask containing carbon and swirl gently until the carbon is completely wetted

5. Place flask on a hot plate and bring the contents to a boil

6. Remove the flask from the hot plate and cool to room temperature

7. Pipet 100.0 ml of 0.100 N iodine solution into flask and shake the contents vigorously for 30±1 sec

8. Quickly filter mixture by gravity through one sheet of folded filter paper (Whatman No. 42) into a beaker

9. For filtrate was collect 20 to 30 ml. to rinse a pipet, the remaining filtrate was collect by clean beaker

10. Titrate filtrate with standardized 0.100 N sodium thiosulfate solution until the solution is a pale yellow

11. Add 1-2 drops of starch indicator solution and continue the titration with sodium thiosulfate until colorless solution

12. Record the volume of sodium thiosulfate used

13. Calculate iodine number

Appendix D

Moisture

- Weight sample 2 g with analytical balance

- Heating the sample at 110 ° C for 3 hours

- Cooling this sample in desicator to ambient temperature and weight again

$$\%moisture \quad = \quad \frac{loss \quad weight \times 100}{original \quad weight} \tag{D.1}$$

Appendix E

IR spectrum
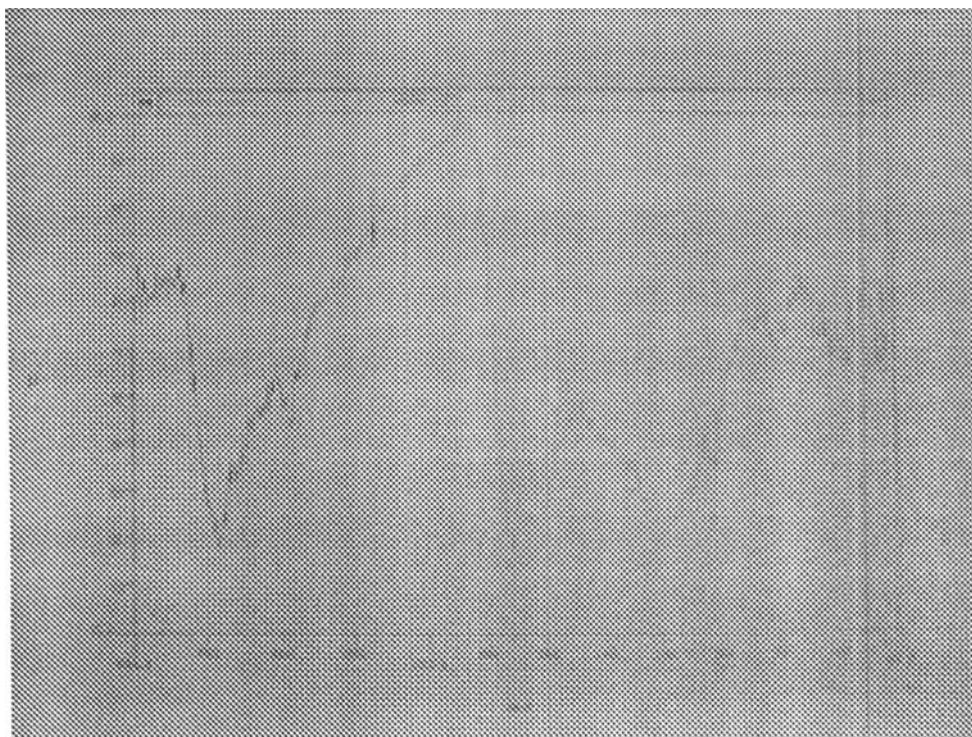
Figure E.1: Spectrum of carbon adsorbent which activated with sulfuric acid
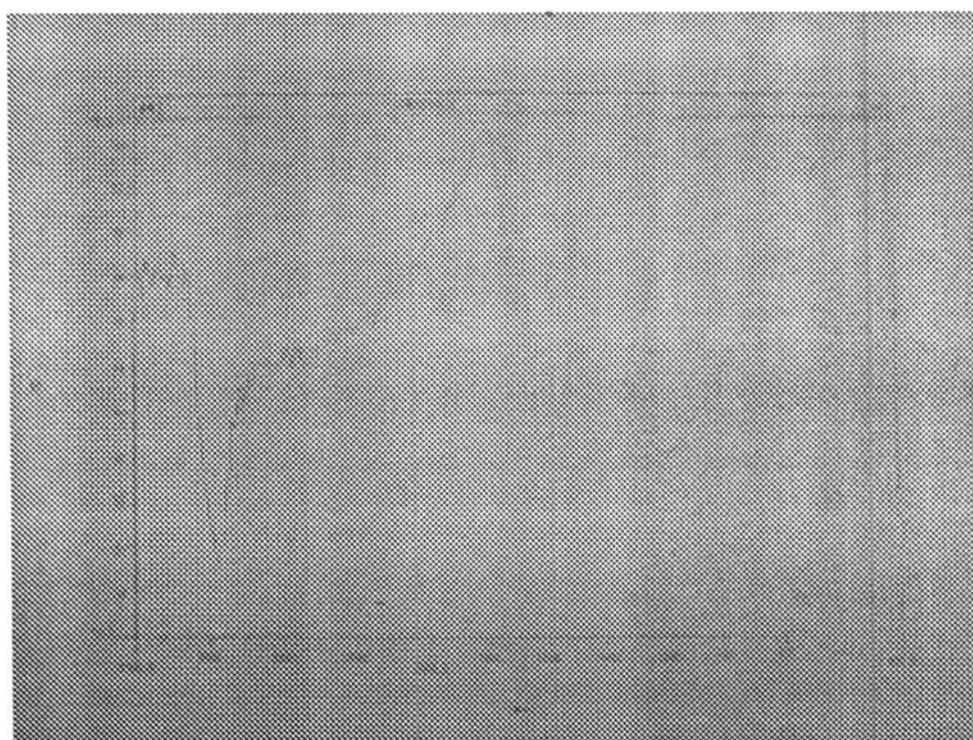
Figure E.2: Spectrum of carbon adsorbent which activated with 20% phosphoric acid
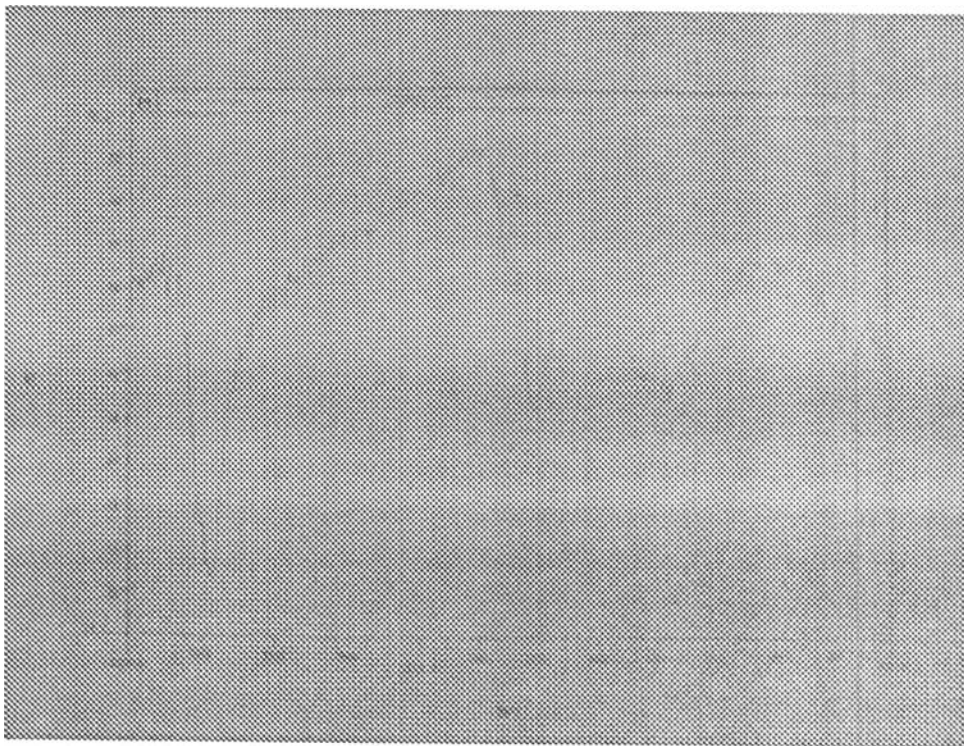
Figure E.3: Spectrum of carbon adsorbent which activated with 50% phosphoric acid

Appendix F

The retention time and varience

Table F.1: The retention time and varience on various adsorbents

adsorbate	adsorbent	T($^\circ$C)	Q,ml/min	t_r, sec	varience, sec^2
benzene	H$_2$SO$_4$	150	52	94.26	7578.98
			63	79.62	6496.35
			73	66.63	4709.81
			83	60.53	4517.92
			94	63.08	5605.54
			104	62.23	4995.79
		180	21	72.92	3117.99
			31	49.50	1759.95
			52	38.33	1303.87
			63	29.42	964.37
			73	35.639	1353.61
		190	21	44.89	950.40
			31	40.14	641.93
			42	24.56	410.05
			63	18.51	193.66
			73	15.13	174.54
		200	21	37.36	799.36
			31	26.32	286.82
			42	18.72	173.09
			63	12.99	146.05
			73	13.53	195.34
	20%H$_3$PO$_4$	180	21	168.82	13873.09
			31	113.15	8864.81
			42	90.55	6537.58
			52	81.45	6152.69
			63	74.68	5737.01
			73	61.53	4131.05
		190	21	131.03	8277.60
			31	93.05	5738.48

continued from previous page

adsorbate	adsorbent	T(°C)	Q,ml/min	t_r, sec	varience, sec^2
			42	84.18	6204.68
			52	62	3045.59
			63	53.74	2630.49
			73	47.56	2317.78
		200	21	90.60	6904.76
			42	56.26	2733.90
			48	39.22	1852.99
			63	37.81	1607.48
			73	26.98	774.77
			84	25.17	881.32
		210	21	36.84	1130.24
			42	21.2	434.33
			52	16.15	104.18
			60	12.4	82.56
			73	12.48	94.31
	50%H_3PO_4	150	42	187.98	37824.79
			52	176.04	21054.45
			63	150.56	18674.98
			73	152.95	19092.64
			94	126.51	12136.61
		180	52	53.63	2233.26
			63	46.82	1804.15
			73	42.45	1663.16
			83	37.28	1133.19
			94	32.5	923.26
			104	32.72	914.44
		200	21	50.92	1798.78
			31	30.29	646.78
			42	21.95	380.37
			63	18.83	252.3
			73	14.96	123.02
			84	14.61	130.63
		210	26	40.01	1052.61
			31	41.77	952.07
			42	33.19	581.31
			52	24.69	309.98
			63	22.1	355.09
	$ZnCl_2$	150	73	485.97	107064.69
			83	482.42	85893.17
			94	426.32	76330.03
			104	391.81	63336.62
		180	52	142.1	11137.41
			63	125.80	7666.81

continued from previous page

adsorbate	adsorbent	T(°C)	Q,ml/min	t_r, sec	varience, sec^2
			83	121.68	7877.69
			94	93.46	3352.43
			104	80.55	2884.23
		190	52	117.42	6549.82
			63	94.08	5007.49
			73	84.15	3845.3
			83	67.92	2242.49
			94	63.81	2644.36
			104	66.24	2752.16
		200	21	108.65	6075.03
			26	93.79	3717.08
			42	59.38	1112.19
			52	49.31	1160.87
			63	42.49	636.97
		210	31	59.47	906.85
			42	59.71	861.48
			52	37.82	520.47
			63	40.87	349.17
			73	32.27	364.62
toluene	H_2SO_4	180	52	153.19	18886.94
			63	113.36	13917.52
			73	105.04	10404.8
			83	93.22	9316.09
			94	66.49	5860.92
			104	71.25	3933.37
		190	21	220.37	21735.73
			26	190.02	25296.68
			31	154.64	13874.89
			42	119.89	11640.05
			52	106.74	11507.85
			63	68.46	4084.61
		200	21	138.43	7835.36
			26	123.16	4441.62
			42	75.11	3311.43
			63	39.85	998.87
	20% H_3PO_4	180	63	1467.9	1087391.53
			73	1186.47	778987.89
			83	1053.75	61875.96
			94	920.55	465541.69
		190	73	731.41	300498.3
			83	569.6	167574.69
			94	470.67	104708.06
			104	453.03	107297.86

continued from previous page					
adsorbate	adsorbent	T(°C)	Q,ml/min	t_r, sec	varience, sec^2
		200	52	608.22	185749.32
			63	524.46	148308.53
			73	485.46	136484.75
			83	400.49	99199.08
			94	362.74	77484.56
		210	31	636.95	152702.08
			42	473.57	117214.69
			52	411.59	94082.45
			63	355.92	76155.31
			73	273.12	42013.54
			83	199.26	28509.51
	20% H_3PO_4	180	52	472.49	129000.11
			63	421.75	118364.42
			73	347.31	72893.97
			83	312.29	58095.82
			94	268.02	42366.05
			104	243.59	38637.27
		190	42	396.51	53208.65
			52	372.55	45167.8
			62	263.45	233341.84
			83	206.24	19352.65
			93	201.06	20258.21
		200	41	211.46	19690.91
			52	176.93	13187.64
			62	156.7	11842.24
			73	143.84	9328.66
			93	124.68	6915.9
		210	20	230.48	23309.38
			41	146.6	11705.04
			50	98.06	5617.5
			62	91.1	5330.73
			73	82.3	4683.23
			93	68.92	2852.73
	$ZnCl_2$	180	52	1603.29	777679.64
			63	1480.22	75934.53
			73	1267.26	499068.64
			83	1101.76	371833.27
		190	52	996.1	310647.79
			73	777.32	192954.64
			83	716.16	175643.55
			94	638.93	153383.52
		200	52	751.16	202633.84
			63	655.11	162113.46
					continued on next page

continued from previous page					
adsorbate	adsorbent	T(°C)	Q,ml/min	t_r, sec	varience, sec^2
			73	581.81	130258.87
			83	528.86	117052.28
			94	485.71	93228.87
		210	63	522.07	118661.59
			73	469.03	94833.22
			83	410.68	70496.43
			94	365.35	56908.73
			104	362.29	54927.22
o-xylene	H_2SO_4	180	31	407.19	94267.91
			42	289.65	55667.18
			52	186.19	27684.72
			63	173.43	28160.99
			73	139.17	18843.31
		190	31	276.56	41434.76
			42	208.92	27667.72
			63	119.07	11601.53
			73	118.12	12591.77
			83	110.3	10876.22
		200	26	195.77	22854.51
			31	171.53	13506.75
			42	127.74	11952.24
			52	87.71	4844.8
			63	83.35	5059.57
		210	26	116.85	9142....41
			31	91.5	6207.91
			52	52.5	2467.82
			59	53.03	2005.66
	20% H_3PO_4	180	63	1854.85	1377327.63
			73	925.04	371740.41
			83	803.37	238758.24
			94	573.08	145719.62
		190	83	975.73	501923.62
			89	962.83	464826.55
			94	920.52	424384.2
			99	579.38	178424.17
		200	52	866.35	529608.44
			73	739.55	508609.78
			83	728.64	287032.36
			104	474.8	172231.81
		210	63	530.04	137268.8
			71	499.44	124038.49
			83	473.21	105180.53
			104	388.82	66181.2
					continued on next page

adsorbate	adsorbent	T($^\circ$C)	Q,ml/min	t_r, sec	varience, sec^2
	50% H_3PO_4	180	52	1952.43	1655185.45
			63	1167.32	702909.54
			83	773.95	360368.27
			104	805.79	374392.7
		190	52	1629.57	1300502.70
			73	937.88	398041.45
			83	926.25	412135.91
			94	905.82	417522.31
			104	651.27	204756.1
		200	52	1090.53	780264.37
			73	928.87	589079.09
			83	700	351683.57
			94	548.90	188959.06
			104	599.74	259862.14
		210	52	1027.6	775663.56
			63	992.39	836664.69
			73	872.13	590364.13
			83	732.39	463083.03
			104	548.14	273442.41
	$ZnCl_2$	180	52	605.77	315727.29
			63	598.11	394115.73
			83	302.72	98829.07
			94	298.02	73587.18
			104	171.78	25011.12
		190	52	322.78	87684.87
			63	320.65	121166.28
			73	227.45	46678.61
			94	203.74	53959.74
			104	121.37	11751.58
		200	52	77.4	5625.92
			63	75.14	4336.44
			73	68.02	3494.88
			83	54.82	2371.06
			94	47.05	1914.04
			104	36.34	1402.65
		210	52	100.16	3692.12
			63	87.16	2163.91
			73	71.55	1409.20
			83	62.19	1058.81
			94	53.37	849.22
			104	47.72	713.61

Appendix G

The adsorption equilibrium constant

Table G.1: Effect of chemical reagents to adsorption equilibrium constant

adsorbent	adsorbate	T(°C)	K
H_2SO_4	benzene	150	95.2381
		180	31.1580
		190	24.0385
		200	19.2963
	toluene	180	234.8898
		190	116.1824
		200	83.1654
		210	62.6875
	o-xylene	180	403.7027
		190	236.5503
		200	144.5005
		210	81.3166
$20\%H_3PO_4$	benzene	180	521.2090
		190	417.6410
		200	314.3390
		210	126.6280
	toluene	180	17801.6210
		190	12345.3190
		200	5037.7360
		210	3569.8710
	o-xylene	180	40827.9120
		190	33295.0623
		200	6131.0691
		210	3761.9846
$50\%H_3PO_4$	benzene	150	1815.2472
		180	935.7010
		200	394.2345

continued from previous page			
adsorbent	adsorbate	T(°C)	K
		210	357.5740
	toluene	180	9601.3160
		190	6614.5060
		200	2602.9170
		210	1748.5010
	o-xylene	180	48147.467
		190	37899.668
		200	23181.447
		210	20601.512
ZnCl$_2$	benzene	150	7801.5411
		180	1859.3581
		200	682.8713
		210	174.6940
	toluene	180	36593.2383
		190	21392.8711
		200	17810.9536
		210	14131.4741
	o-xylene	180	2593.3
		190	987.23
		200	312.52
		210	241.81

Table G.2: Effect of activation temperature to adsorption equilibium constants

column temperature, (° C)	activation temperature, (° C)				
	150	200	250	300	350
180	1053	999	585		
190	864	678	533	352	284
200	713	317	275	263	212
210	429	276	233	230	134
220				204	78

Appendix H

The particle density

Table H.1: The data for determination particle density

adsorbent	L, cm	dP	$Q \times 10^6$	G_o	Re	$-dPD_p/(G_o 2L)$
H_2SO_4	10.4	0.0977	1.7452	0.0173	0.3073	17901.2934
		0.1535	3.0426	0.0301	0.5347	955.8501
		0.2298	3.9568	0.0392	0.6963	8668.606
		0.2512	5.8997	0.0584	1.0374	4384.5748
		0.2807	7.6923	0.0761	1.3518	2961.2051
		0.3743	8.2821	0.082	1.4566	3487.9053
$20\%H_3PO_4$	9.2	0.0307	3.0012	0.0297	0.5276	2135.8215
		0.0758	4.5005	0.0445	0.7905	2415.973
		0.0811	6.7476	0.0668	1.1866	1178.91
		0.1208	8.3472	0.0826	1.4672	1179.4339
		0.1395	10.3413	0.1024	1.8189	909.4853
		0.1747	12.0265	0.119	2.1138	864.9493
$50\%H_3PO_4$	12.3	0.3223	1.3528	0.0937	1.7765	798.1539
		0.5419	2.4272	0.1679	3.1837	419.0056
		1.1976	6.8775	0.4765	9.0334	116.9309
		1.4579	7.924	0.549	10.4058	107.6811
$ZnCl_2$	8.9	1.2204	4.5662	0.0445	0.78222	2810.8516
		1.7153	6.2369	0.0608	1.0688	1895.3564
		2.2103	7.9083	0.0771	1.3553	1789.8744
		2.5531	9.7752	0.0952	1.6734	1391.6452

Appendix I

The properties of carbon adsorbents

Table I.1: The physical properties of carbon adsorbents activated which various chemical reagents

reagent	T ° C	physical properties		
		%moisture	I_2 no.	%yield
H_2SO_4	250	2.0	234	53
20%H_3PO_4	300	2.1	296	43.8
30%H_3PO_4	300	3.0	320	43.7
40%H_3PO_4	300	2.9	395	46.7
50%H_3PO_4	300	3.8	521	48.9
$ZnCl_2$	600	1.5	1242	44.2

Appendix J

The axial dispersion coefficients

Table J.1: Axial dispersion coefficient of aromatics on various adsorbents

adsorbent	adsorbate	T(°C)	D_L,(1/sec)	D_{AB},(1/sec)
H_2SO_4	benzene	150	10.2240	0.1737
		180	5.3056	0.1968
		190	5.0524	0.2048
		200	5.8332	0.2129
	toluene	180	18.6460	0.1782
		190	3.0455	0.1854
		200	3.1919	0.1928
		210	3.1079	0.2003
	o-xylene	180	4.5585	0.1617
		190	6.0611	0.1682
		200	7.0378	0.1749
		210	9.3605	0.1817
$20\%H_3PO_4$	benzene	180	0.4346	0.1968
		190	0.4945	0.2048
		200	1.3055	0.2129
		210	1.7698	0.2212
	toluene	180	1.8220	0.1782
		190	3.5645	0.1854
		200	1.4342	0.1928
		210	0.5604	0.2003
	o-xylene	180	1.6665	0.1617
		190	2.8211	0.1682
		200	2.8928	0.1749
		210	2.6648	0.1817
$50\%H_3PO_4$	benzene	150	1.7983	0.1737
		180	1.2203	0.1968
		200	0.5903	0.2129
		210	0.6047	0.2212

continued from previous page				
adsorbent	*adsorbate*	T(°)	D_L,(1/sec)	D_{AB},(1/sec)
	toluene	180	0.9175	0.1782
		190	0.3017	0.1854
		200	0.5978	0.1928
		210	0.2882	0.2003
	o-xylene	180	0.4727	0.1617
		190	0.8376	0.1682
		200	1.0687	0.1749
		210	1.0279	0.1817
$ZnCl_2$	benzene	150	1.4834	0.1737
		180	1.5197	0.1968
		190	0.8250	0.2048
		200	0.5857	0.2129
		210	0.2982	0.2212
	toluene	180	0.3795	0.1782
		190	0.3208	0.1854
		200	0.6608	0.1928
		210	0.7017	0.2003
	o-xylene	180	32.5210	0.1617
		190	14.9480	0.1682
		200	14.5010	0.1749
		210	29.2120	0.1817

CURRICULUM VITAE

Supaporn Munsaithong is at the Department of Chemical Engineering, Chulalongkorn University Bangkok. She has a B.S. in chemistry from faculty of Science Mahidol University(1995). Subsequently, she completed the requirement for M.S. degree in Chemical Engineering at the Department of Chemical Engineering, Faculty of Engineering, Chulalongkorn Universityin 1998.