REFERENCES

Ali Beg, M. A. and Usmami, T. H. 1985. Low ash activated carbon from rice husk. Pakistan J. Sci. Ind. Res. 28(4): 285–287.

Bernardin, Jr., F. E. n.d. Experimental design and testing of adsorption and adsorbates. In Slejko, F. L. Adsorption technology: A step-by-step approach to process evaluation and application. New Jersey: Tall Oaks.

Bernardo, E. C.; Egashira, R.; and Kawasaki, J. 1997. Treatment of wastewater from sugar industries using activated carbon from cane bagasse. In Proc. Regional Symposium on Chemical Engineering (Johor, Malaysia). pp. 150-156.

Bird, R. B.; Stewart, W. E.; and Lightfoot, E. N. 1960. Transport Phenomena. NY: John Wiley & Sons.

Breck, D. W. 1974. Zeolite molecular sieves. N.Y.: John Wiley & Sons. pp. 636-650.

Carleton, F. B.; Kershenbaum, L. S.; and Kakeham, W. A. 1978. Adsorption in non-isobaric fixed-beds. Chem. Eng. Sci. 33: 1239-1246.

Chatzopoulos, D.; Varma, A.; and Irvine, R. L. 1993. Activated carbon adsorption and desorption of toluene in the aqueous phase. AIChE Journal 39(12): 2024-41.

Chihara, K.; Suzuki, M.; and Kawazoe, K. 1978. Adsorption rate on molecular sieving carbon by chromatography. AIChE Journal 24(12): 237-246.

Chirasak Sangpoum, Deacha Chatsiriwech, and Vichitra Chongvisal. 1998. Effects of temperature and period on characteristics of adsorbents from water hyacinth activated with zinc chloride. In Proc. Regional Symposium on Chemical Engineering (Quezon City, Philippines). October 14–16. p. 396.

Davini, P. 1990. Adsorption and desorption of SO_2 on active carbon: The effect of surface basic groups. Carbon 28(4): 565–571.

Do, D. D. and Wang, K. 1998. Dual diffusion and finite mass exchange model for adsorption kinetics in activated carbon. AIChE Journal 44(1): 68-81.

Gilmer, H. B. and Kobayashi, R. 1965. The study of multicomponent gas-solid equilibrium at high pressures by gas chromatography. AIChE Journal 11 (4): 702-705.

Girgis, B. S.; Khalil, L. B.; and Tawfik, T. A. M. 1994. Activated carbon from sugarcane bagasse by carbonization in the presence of inorganic acids. J. Chem. Tech. Biotechnol 61: 87–92.

Goebel, J. C.; Booij, K.; and Fortuin J. M. H. 1986. Axial dispersion in sinple-phase flow in pulsed packed columns. Chemical Engineering Science 41(12): 3197-3203.

Gopal, B. 1987. Water hyacinth. Amsterdam: Elsevier.

Grajek, Z. W. H. and Jankowska, H. 1997. Application of Kovats retention indixed for investigation of adsorption properties of activated carbons. J. of Chromatography A 782: 87–94.

Han, N. W.; Bhakta, J.; and Carbonell, R. G. 1985. Longitudinal and lateral dispersion in packed bed: Effects of column length and particle size distribution. AIChE Journal 31(2): 277-288.

Haynes, Jr., H. W. 1986. An analysis of sorption heat effects in the pulse gas chromatography diffusion experiment. AIChE Journal 32(10): 1750-1753.

Haynes, Jr., H. W. 1999. Removal of sugar colorants by granular activated carbons made from binders and agricultural by-products. Bioresource Technology 69: 45-51.

Hufton, J. R. and Danner, R. P. 1990. Gas-solid diffusion and equilibrium parameters by tracer pulse chromatographic. Chemical Engineering Science 46(8): 2079-2091.

Hufton, J. R. and Danner, R. P. 1993. Chromatographic study of alkanes in silicalite: Equilibrium properties. AIChE Journal 39(6): 954-961.

Hyun, S. H. and Danner, R. P. 1985. Adsorption equilibrium constants and intraparticle diffusivities in molecular sieves by tracer-pulse chromatography. AIChE Journal 31(7): 1077-1085.

Jasra, R. V. and Bhat, S. G. T. 1988. Adsorptive bulk separations by zeolite molecular sieves. Separation Science and Technology 23(10&11): 945-989.

Juang, R. S.; Wu, F. C.; and Tseng, R. L. 1996. Adsorption isotherms of phenolic compounds from aqueous solutions onto activated carbon. J. Chem. Eng. Data 41: 487-492.

Kaul, B. K. 1987. Modern version of volumetric apparatus for measuring gas-solid equilbrium data. Ind. Eng. Chem. Res. 26: 928-933.

Kazuyuki Chihara, M. S. and Kawazoe, K. 1978. Adsorption rate on molecular sieving carbon by chromatographic. AIChE J. 24(2): 237-246

Keller II, G. E.; Anderson, R. A.; and Yon, C. M. 1987. Adsorption. in Handbook of Separation Process Technology. NY: John Wiley & Sons. pp. 644–696.

Khalil, L. B. and Girgis, B. S. 1995. Adsorption of p–nitrophenol on activated carbon prepared from phosphonic acid–treated apricot stone shells. Adsorption Science and Technology 12(1): 79–91.

Laine, J. and Yunes, S. 1992. Effect of the preparation method on the pore size distribution of activated carbon from coconut shell. Carbon 30(4): 601–604.

Lee, C. H.; Byeon, S. H.; and Holder, G. D. 1996. Adsorption characteristics of toluene and naphthalene on silica gel under the subcritical and supercritical conditions using chromatographic techniques. J. of Chemical Engineering of Japan 29(4): 683–694.

Lewis, Sr., R. J. 1993. Hawley's Condensed Chemical Dictionary. 12th ed. NY: Van Nostrand Reinhold.

Malek, A. and Faroon, S. 1997. Kinetics of hydrocarbon adsorption on activated carbon and silica gel. AIChE Journal 43(3): 761-776.

Mantell, C. L. 1945. Adsorption. 1st ed. New York: McGraw–Hill.

Nguyen, C.; Ahmadpour, A.; and Do, D. D. 1995. Effects of gasifying agents on the characterization of nut shell-derived activated carbon.

Noll, K. E.; ASCE, M.; Aguwa, A. A.; Fang, Y. P.; and Boulanger, P. T. 1985. Adsorption of organic vapors on carbon and resin. J. of Environmental Engineering 111(4).

Prakash, J.; Nirmalakhandan, N.; and Sceece, R. E. 1994. Prediction of activated carbon adsorption isotherms for organic vapors. Environ. Sci. Technol. 28 (8): 1403-1409.

Pattamasuda Kulsawate, Chanika Sophonsiri, and Wanwisa Skolpap. 1997. Characterization of activated carbon prepared from palm shell. In Proc. Regional Symposium on Chemical Engineering (Johar, Malaysia) pp.601-605.

Pendyal, B,; Johns, M. M.; Marshall, W. E.; Ahmedna, M.; and Rao, R. M. 1999. The effects of binders and agricultural by-products on physical and chemical properties of granular activated carbons. Bioresource Technology 68: 247-254.

Perry, R. T. and Green, D. W. 1997. Perry's Engineers' Handbook. 7th ed. New York: McGraw-Hill.

Ratchada Rattanamung. 1997. Adsorption of organic solvent vapors on various activated carbons using the chromatographic technique. Master's Thesis, Chulalongkorn University.

Reid, R. C.; Prausnitz, J. M.; and Poling B. E. 1988. The properties of gases & liquid. 4th ed. NY: McGraw-Hill.

Rungrawee Yingyuad. 1997. Effects of types of zeolites on adsorption of organic solvent vapors using the gas chromatographic technique. Master's Thesis, Chulalongkorn University.

Ruthven, D. M. 1984. Principles of adsorption and adsorption processes. NY: John Wiley & Sons.

Schneider, P. and Smith, J. M. 1968. Adsorption rate constants from chromatography. AIChE Journal 14(5): 762-771.

Schneider, P. and Smith, J. M. 1968. Chromatographic study of surface diffusion. AIChE Journal 14(6): 886-895.

Supaporn Munsaithong. 1998. Determination of adsorption of toluene and xylene vapors on activated carbons from corncob using the gas chromatographic technique. Master's Thesis, Chulalongkorn University.

Suzuki, M. 1990. Adsorption Engineering. Japan: Kodansha.

Suzuki, M. and Smith, J. M. 1972. Axial dispersion in beds of small particles. Chem. Eng. Journal 3: 256-264.

Wildman, J. and Derbyshire, F. 1991. Origins and functions of macroporosity in activated carbons from coal and wood precursors. Fuel 70: 655-661.

Yehaskel, A. 1978. Activated carbon: Manufacture and regeneration. New Jersey: Noyes Data Corporation.

Yun, J. H. and Choi, D. K. 1997. Adsorption isotherms of benzene and methylbenzene vapours on activated carbon. J. Chem. Eng. Data 42(5) 894-896.

Weber, Jr., W. J. n.d. Adsorption theory, concept and models. In Slejko, F. L. Adsorption technology: A step-by-step approach to process evaluation and application. New Jersey: Tall Oaks.

REFERENCES IN THAI

Anuchit Kitsawas. 1977. The study of producing activated carbon from rice husk by using zinc chloride as an activating reagent. Documentary. pp. 11-14. Department of Science Service.

Boonchai Thakunmahachai. 1991. Production of activated carbons from palmyra palm shell in fluidized bed. Master's Thesis, Chulalongkorn University.

Boonthida Kositsup. 1991. Leaf protein concentration from water hyacinth (*Eichhornia crassipes (Mart.) Solms*). Master's Thesis, Chulalongkorn University.

Inthira Harnphongphan. 1995. General chemistry for engineering undergrad. 5th ed. Bangkok: Chulalongkorn University Press.

Sugar-Cane and Sugar Administration, The. 1996. The byproducts of sugar-cane and sugar industries. J. of Sugar 2(4): 1–4.

Kadesucha Pulkham. 1993. Heavy metal removal by ion exchange resin made from bagasse and water hyacinth. Master's Thesis, Chulalongkorn University.

Kesara Nutalai, et al. n.d. The production of activated carbon from soil in laboratory. J. of Science and Technology: 50–86.

Kittiya Suasinask. 1999. Adsorption of propane with carbon adsorbent from coconut shell activated by zinc chloride. Master's Thesis, Chulalongkorn University.

Kriangsak Kittiphiman. 1999. Adsorption of oxygen and nitrogen with activated carbons from coconut shell activated by zinc chloride. Master's Thesis, Chulalongkorn University.

Narong Wutsatian. 1986. Treatments of industrial and boiler water. Bangkok: H. N. Publishing.

Phasuk Kongchatree, Borisut Suttisong, Aroon Kongkeo, and Kesara Nutalaya. 1992. A comparative study of activated carbons from coconut shell, palmyra palm meat, and cashew nut shell. Project No. Pho.30-14/Report No. 3. Thailand Institute of Scientific and Technological Research.

Pongsathorn Kaokachathorn. 1995. Activated carbon from corncob. Master's Thesis, Chulalongkorn University.

Sakkhee Sansupa. 1985. Gasification of rice hulls in a double fluidized bed system. Master's Thesis, Chulalongkorn University.

Science Service, Department of. 1980. The study of producing activated carbon from rice husk by using zinc chloride as an activating reagent. The Activity Report of Department of Science 38: 54–73.

Science Service, Department of. 1985. Activated carbon. Department of Science's News 107(1): 11–12.

Wisarut Lochananon. 1999. Effects of carbon adsorbent preparation from groundnut shell by phosphoric acid on adsorption of dilute benzene vapour. Master's Thesis, Chulalongkorn University.

APPENDICES

APPENDIX A

EXAMPLE OF CALCULATION

A.1 EVALUATION OF MOMENTS OF THE CHROMATOGRAM

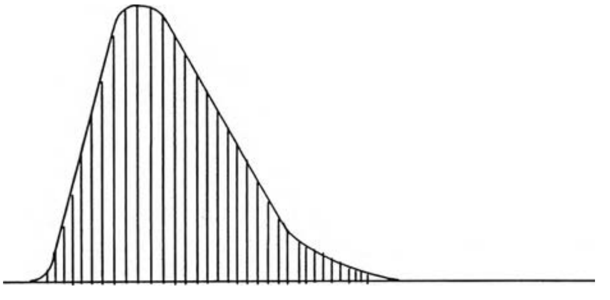

Figure A.1 Chromatogram of the experiment result

Figure A.1 shows an example of experimental chromatogram of the effluent from the adsorption column. The chromatogram was divided into small sliced area (about 1 mm width) in order to determine the zero moment or the area of the chromatogram, the first absolute and second central moments from the following equations, respectively.

zero moment $$\text{area} \approx \Sigma c_i \Delta t_i \tag{A.1}$$

first absolute moment $$t_R \approx \frac{\sum t_i c_i \Delta t_i}{\sum c_i \Delta t_i} \tag{A.2}$$

second central moment $$\sigma^2 \approx \frac{\sum (t_i - t_R)^2 c_i \Delta t_i}{\sum c_i \Delta t_i} = \frac{\sum t_i^2 c_i \Delta t_i}{\sum c_i \Delta t_i} - t_R^2 \tag{A.3}$$

A.2 CALCULATION OF ADSORPTION EQUILIBRIUM CONSTANTS

The adsorption equilibrium constant is calculated from the equation 2.10 by the plot of t_R versus L/v such as shown in Figure A.2.

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

The slope of the straight line is equal to 1 + $(1-\varepsilon)K/\varepsilon$ which is used in calculation equilibrium constant calculation.

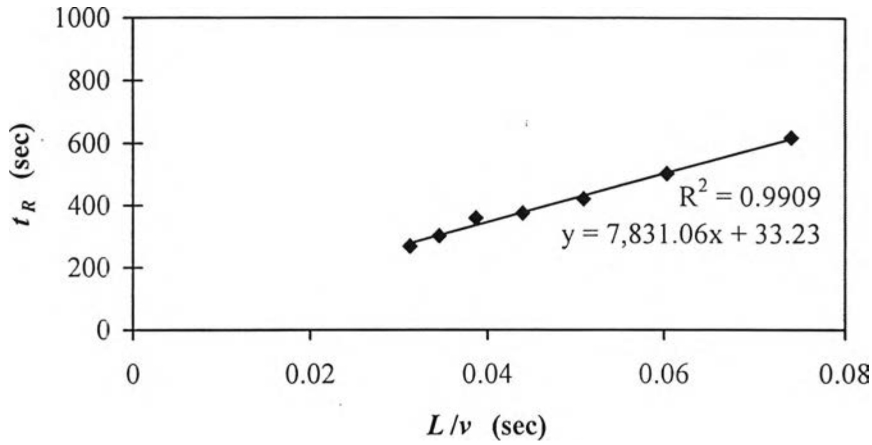

Figure A.2 First moment plot of adsorption of toluene vapour on WH401 at 180°C

Therefore, the adsorption equilibrium constant could be obtained from

$$K = (\text{slope}-1)\left(\frac{\varepsilon}{1-\varepsilon}\right) \qquad \text{(A.4)}$$

The bed porosity of WH401 is 0.2958, hence the adsorption equilibrium constant on WH401 is

$$K = (7831.06 - 1)\left(\frac{0.2958}{1 - 0.2958}\right)$$

$$K = 3{,}288.54$$

A.3 CALCULATION OF HEAT OF ADSORPTION

From van't Hoff equation,

$$\frac{\mathrm{d}\ln K}{\mathrm{d}T} = \frac{\Delta H}{RT^2}$$

it could be integrated with an assumption of constant heat of adsorption (ΔH):

$$\int_{K_0}^{K} \mathrm{d}\ln K = \frac{\Delta H}{R}\int_{T_0}^{T} \frac{1}{T^2}\mathrm{d}T$$

$$\ln K = \ln K_0 + \frac{-\Delta H}{R(T - T_0)}$$

$$\ln K = \ln K_0 + (-\Delta H/RT) \qquad \text{(A.5)}$$

The plot of ln K versus $1/T$ is illustrated in Figure A-3. To find the heat of adsorption, the slope of the straight line is used.

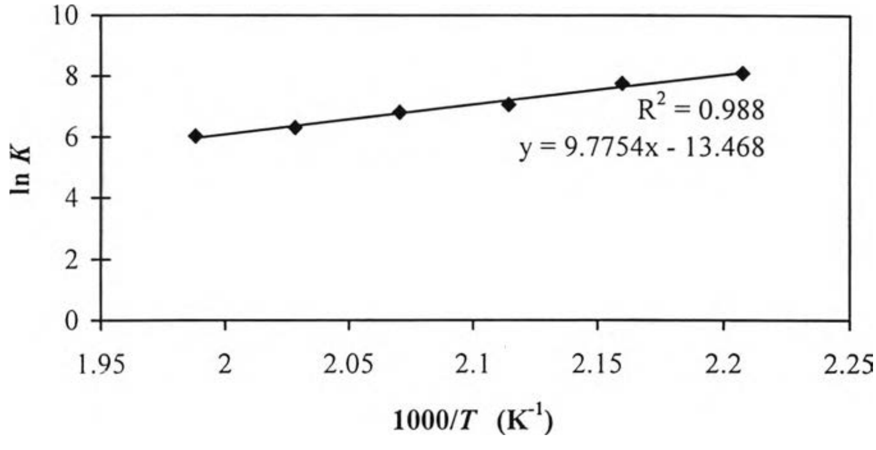

Figure A.3 Adsorption equilibrium constant of toluene vapour on WH401 at 180°C

Therefore,

$$-\Delta H = \text{slope} \times R$$
$$= 9.7754 \times 8.314$$
$$= 81.27 \ \text{kJ/kmol}$$

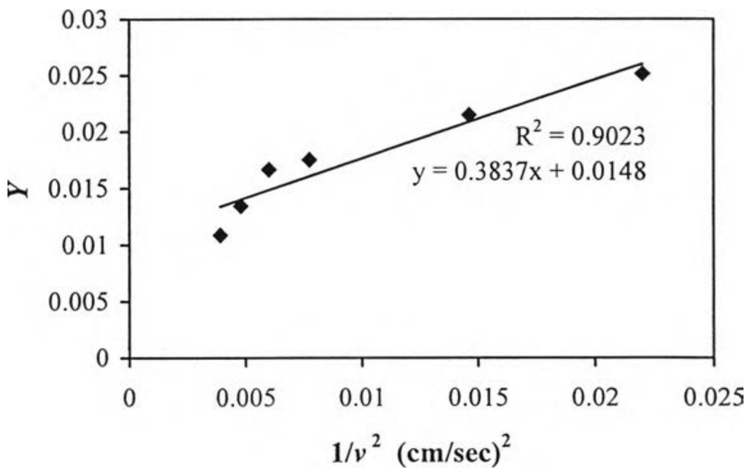

Figure A.4 Overall mass-transfer coefficients of toluene vapour on WH401 at 180°C

A.4 CALCULATION OF OVERALL MASS-TRANSFER COEFFICIENTS

From equation,

$$\frac{\sigma^2}{2t_R^2} = \frac{D_L}{vL} + \frac{v}{L}\left(\frac{\varepsilon}{1-\varepsilon}\right)\frac{1}{kK}\left[1+\frac{\varepsilon}{(1-\varepsilon)K}\right]^{-2} \tag{A.6}$$

rearrange the equation, we obtain

$$\frac{\sigma^2}{2t_R^2}\frac{L}{v} = \frac{D_L}{v^2} + \left(\frac{\varepsilon}{1-\varepsilon}\right)\frac{1}{kK}\left[1+\frac{\varepsilon}{(1-\varepsilon)K}\right]^{-2} \tag{A.7}$$

The plot of $\sigma^2 L/(2t_R^2 v)$, which is referred as Y, versus $1/v^2$ should be linear as shown in Figure A.4. The overall mass-transfer coefficient is calculated from the intercept of line and the slope is corresponding to axial dispersion coefficient.

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

or

$$k = \frac{1}{\text{intercept}}\left(\frac{\varepsilon}{1-\varepsilon}\right)\frac{1}{K}\left[1+\frac{\varepsilon}{(1-\varepsilon)K}\right]^{-2}$$

Therefore, the overall mass-transfer coefficient of toluene vapour adsorption on WH401 at 180°C is;

$$k = \frac{1}{0.0148}\left(\frac{0.2958}{1-0.2958}\right)\frac{1}{3288.54}\left[1+\frac{0.2958}{(1-0.2958)3288.54}\right]^{-2}$$

$$= 0.0128 \text{ sec}^{-1}$$

The axial dispersion coefficient is

$$D_L = \text{slope} = 0.3837 \text{ cm}^2/\text{sec} = 23.022 \text{ cm}^2/\text{min}$$

A.5 CALCULATION OF CONCENTRATIONS OF TOLUENE VAPOUR

From equation, $\log P^{vap} = A - B/(C + t)$ (A.8) where P^{vap} = vapour pressure, mmHg

t = temperature, °C

Substitute toluene data in equation A.8, we obtain

$$\log P^{vap} = 6.95464 - 1344.80/(219.482 + 30)$$
$$= 1.5643$$
$$P^{vap} = 10^{1.5643}$$
$$= 36.6691 \text{ mmHg}$$

$$\% \text{ toluene} = \frac{\text{Partial pressure of toluene}}{\text{Absolute pressure}} \times 100$$
$$= 36.6691 \times 100 / 760$$
$$= 4.82$$

Estimate the injection concentration in the carrier-gas flow

Minimum flow rate 20 ml/min

Amount of injection 100 μl

Time of injection 2 sec

Volume of carrier within 2 sec = 0.6870 cm^3

Amount of benzene in 100 μl = 0.159/100

= 0.0159 cm^3

% by volume of benzene = 0.0159/0.6870 × 100

= 2.31

Amount of toluene in 100 μl = 0.0482/100

= 0.000482 cm^3

% by volume of toluene = 0.000482/0.6870 × 100

= 0.0701

Amount of o-xylene in 100 μl = 0.012/100

= 0.00012 cm^3

% by volume of o-xylene = 0.00012/0.6870 × 100

= 0.0175

A.6 CALCULATION OF IODINE NUMBER OF CARBON ADSORBENTS (AWWA B600-96 AND AWWA 604-96)

$$\text{Iodine number, mg/g} = \frac{x}{m}D$$

where

$$\frac{x}{m} = \frac{A - (2.2B \times \text{ml of thiosulfate solution used})}{\text{weight of sample (grams)}} \qquad (A.9)$$

= mg iodine adsorbed per gram of carbon

$$C = \frac{N_2 \times \text{ml of thiosulfate solution used)}}{50}$$

N_1 = normality of iodine solution

N_2 = normality of sodium thiosulfate solution

A = $N_1 \times 12693.0$

B = $N_2 \times 126.93$

C = residual filtrate normality

D = correction factor (obtained from Table A.1)

For carbon adsorbent WH403

N_1 = 0.0979 N

N_2 = 0.0993 N

A = 1242.64

B = 12.60

C = (0.0993 × 15.0)/50 = 0.0298

D = 0.9388

so $$\frac{x}{m} = \frac{1242.64 - (2.2 \times 12.60 \times 15.0)}{1.0165} = 813.29$$

∴ Iodine number = (813.29)(0.9338) = 763.52 mg/g

A.7 CALCULATION OF BED POROSITY AND PARTICLE DENSITY

From Blake-Kozeny's equiation [Bird, Stewart, and Lightfoot, 1960]:

$$\log\left(\frac{\Delta P}{\rho_b v^2}\right)\left(\frac{D_p}{L}\right) = -\log\left(\frac{D_p v \rho_b}{\mu}\right) + \log\left(\frac{150(1-\varepsilon)^2}{\varepsilon^3}\right) \qquad \text{(A.10)}$$

The plot of $\log\left(\frac{\Delta P}{\rho_b v^2}\right)\left(\frac{D_p}{L}\right)$ versus $\log\left(\frac{D_p v \rho_b}{\mu}\right)$ that is log f versus log Re as shown in Figure A.5 provides the intercept, $\log\left(\frac{150(1-\varepsilon)^2}{\varepsilon^3}\right)$ which is used in bed porosity and particle density calculations.

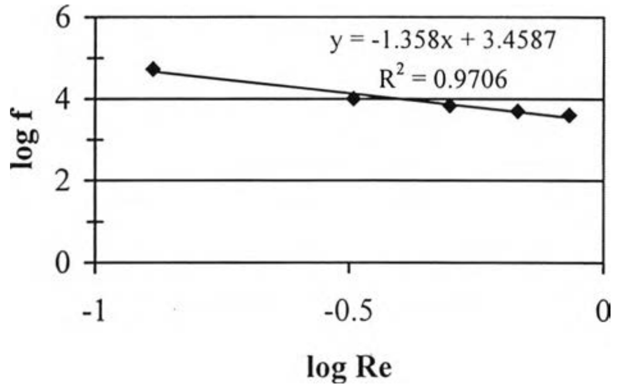

Figure A.5 The relationship of friction factors versus Reynold numbers for flow through packed bed according to Blake-Kozeny equation on WH401T

$$\text{Intercept} \quad \log\left(\frac{150(1-\varepsilon)^2}{\varepsilon^3}\right) = 3.4587$$

$$\left(\frac{150(1-\varepsilon)^2}{\varepsilon^3}\right) = 10^{3.4587}$$

$$\frac{(1-\varepsilon)^2}{\varepsilon^3} = 19.1649$$

$$19.1649\varepsilon^3 - \varepsilon^2 + 2\varepsilon - 1 = 0$$

$$\varepsilon = 0.2958$$

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

$$1 - 0.2958 = \frac{\text{mass/density}}{\pi r^2 \times L}$$

$$0.7042 = \frac{0.0309/\text{density}}{3.147(0.3175)^2 \times 0.5}$$

$$\text{density} = 0.276 \ \text{g/cm}^3$$

Table A.1 Correction factor *D* for iodine number test

Residual Filtrate Normality *C*	0.0000	0.0001	0.0002	0.0003	0.0004	0.0005	0.0006	0.0007	0.0008	0.0009
0.0080	1.1625	1.1613	1.1600	1.1575	1.1550	1.1538	1.1513	1.1500	1.1475	1.1463
0.0090	1.1438	1.1425	1.1400	1.1375	1.1363	1.1350	1.1325	1.1300	1.1288	1.1275
0.0100	1.1250	1.1238	1.1225	1.1213	1.1200	1.1175	1.1163	1.1150	1.1138	1.1113
0.0110	1.1100	1.1088	1.1075	1.1063	1.1038	1.1025	1.1000	1.0988	1.0975	1.0963
0.0120	1.0950	1.0938	1.0925	1.0900	1.0888	1.0875	1.0763	7.0850	1.0838	1.0825
0.0130	1.0800	1.0788	1.0775	1.0763	1.0750	1.0738	1.0725	1.0713	1.0700	1.0688
0.0140	1.0675	1.0663	1.0650	1.0625	1.0613	1.0600	1.0588	1.0575	1.0563	1.0550
0.0150	1.0538	1.0525	1.0513	1.0500	1.0488	1.0475	1.0463	1.0450	1.0438	1.0425
0.0160	1.0413	1.0400	1.0388	1.0375	1.0375	1.0363	1.0350	1.0333	1.0325	1.0313
0.0170	1.0300	1.0288	1.0275	1.0263	1.0250	1.0245	1.0238	1.0225	1.0208	1.0200
0.0180	1.0200	1.0188	1.0175	1.0163	1.0150	1.0144	1.0138	1.0125	1.0125	1.0113
0.0190	1.0100	1.0088	1.0075	1.0075	1.0063	1.0050	1.0050	1.0038	1.0025	1.0025
0.0200	1.0013	1.0000	1.0000	0.9988	0.9975	0.9975	0.9963	0.9950	0.9950	0.9938
0.0210	0.9938	0.9925	0.9925	0.9913	0.9900	0.9900	0.9988	0.9875	0.9875	0.9863
0.0220	0.9863	0.9850	0.9850	0.9838	0.9825	0.9825	0.9813	0.9813	0.9800	0.9788
0.0230	0.9788	0.9775	0.9775	0.9763	0.9763	0.9750	0.9750	0.9738	0.9738	0.9725
0.0240	0.9725	0.9708	0.9700	0.9700	0.9688	0.9688	0.9675	0.9675	0.9663	0.9663
0.0250	0.9650	0.9650	0.9638	0.9638	0.9625	0.9625	0.9613	0.9613	0.9606	0.9600
0.0260	0.9600	0.9588	0.9588	0.9575	0.9575	0.9563	0.9563	0.9550	0.9550	0.9538
0.0270	0.9538	0.9525	0.9525	0.9519	0.9513	0.9513	0.9506	0.9500	0.9500	0.9488
0.0280	0.9488	0.9475	0.9475	0.9463	0.9463	0.9463	0.9450	0.9450	0.9438	0.9438
0.0290	0.9425	0.9425	0.9425	0.9413	0.9413	0.9400	0.9400	0.9394	0.9388	0.9388
0.0300	0.9375	0.9375	0.9375	0.9363	0.9363	0.9363	0.9363	0.9350	0.9350	0.9346
0.0310	0.9333	0.9333	0.9325	0.9325	0.9325	0.9313	0.9313	0.9313	0.9300	0.9300
0.0320	0.9300	0.9294	0.9288	0.9288	0.9280	0.9275	0.9275	0.9275	0.9270	0.9270
0.0330	0.9263	0.9263	0.9257	0.9250	0.9250					

APPENDIX B

SCANNING ELECTRON MICROSCOPE

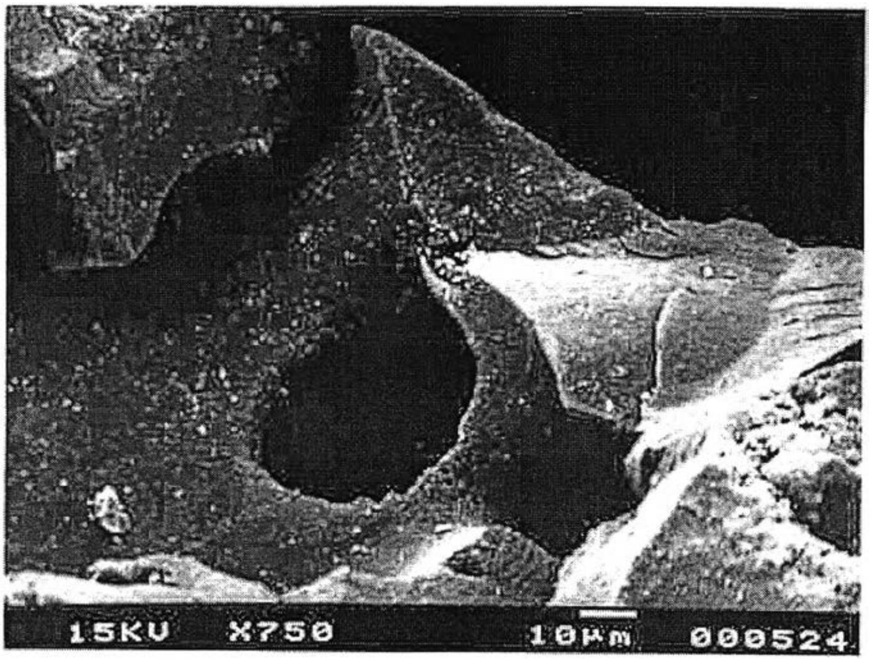

Figure B.1 External surface of carbon adsorbent from WH402

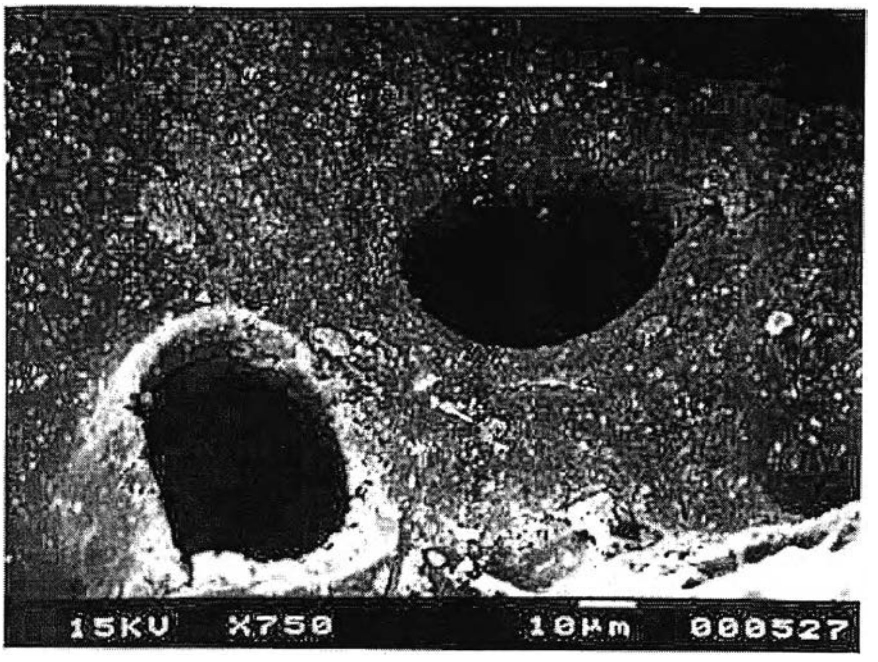

Figure B.2 External surface of carbon adsorbent from WH403

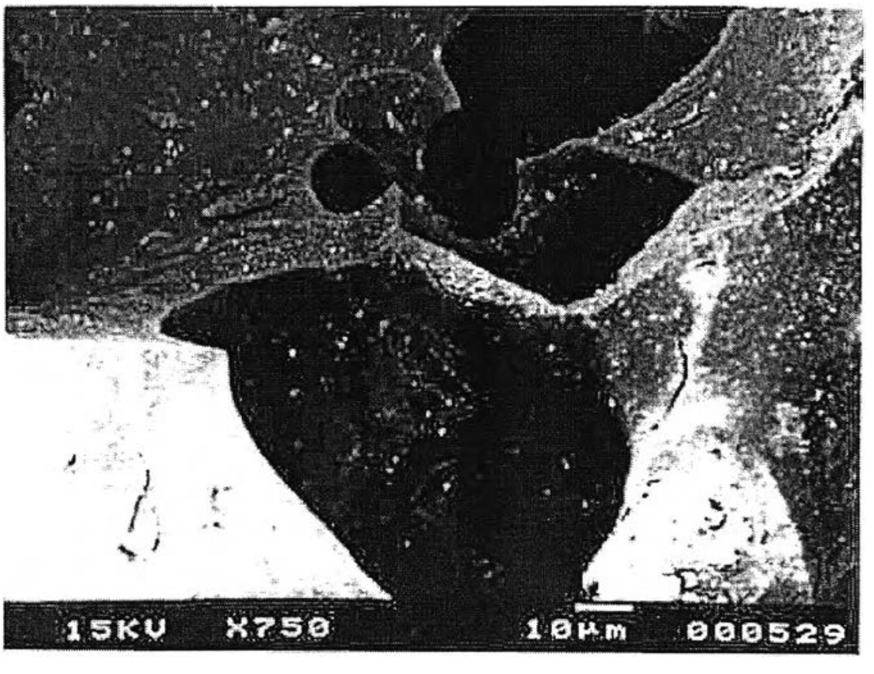

Figure B.3 External surface of carbon adsorbent from WH501

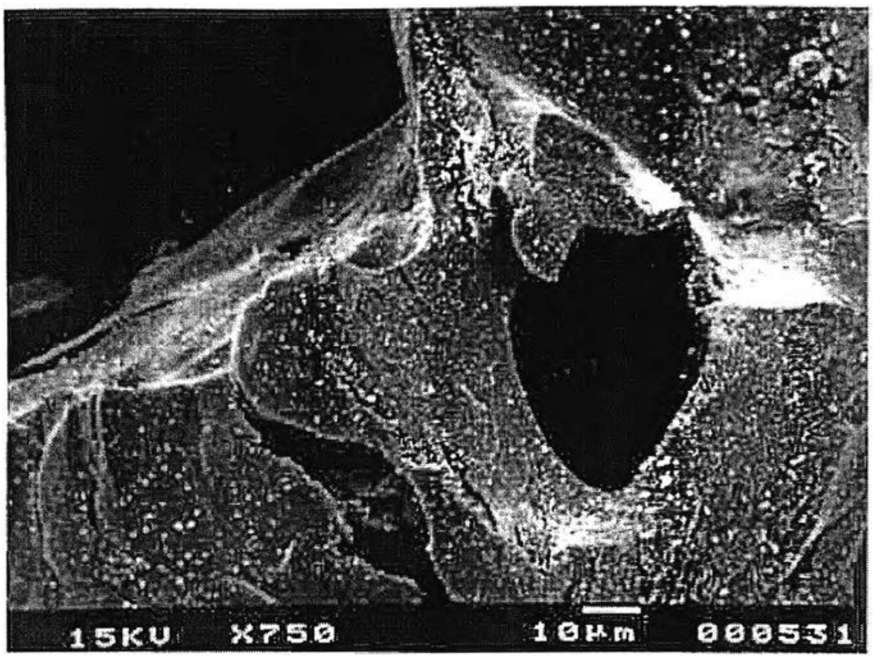

Figure B.4 External surface of carbon adsorbent from WH502

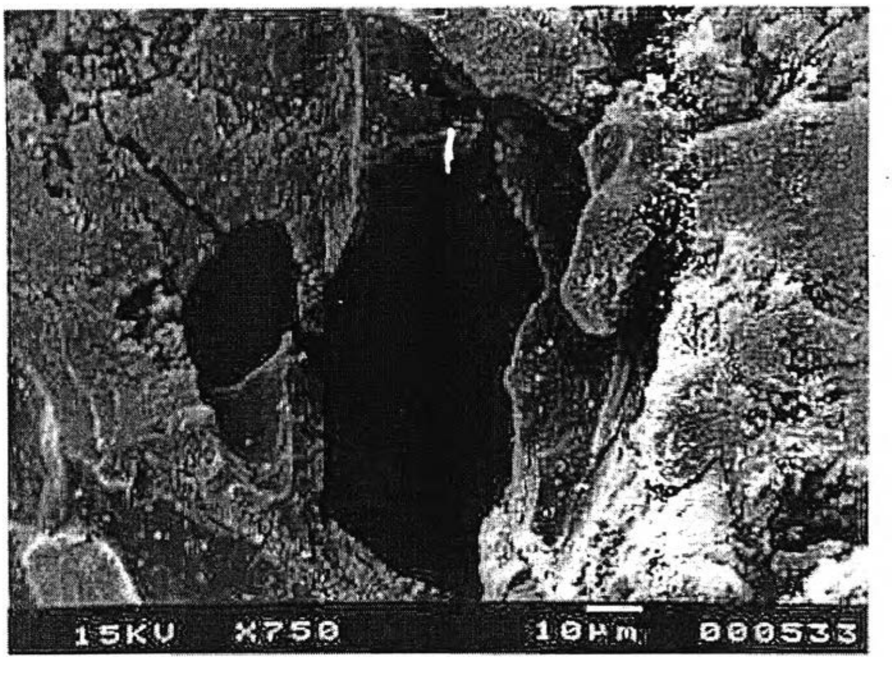

Figure B.5 External surface of carbon adsorbent from WH503

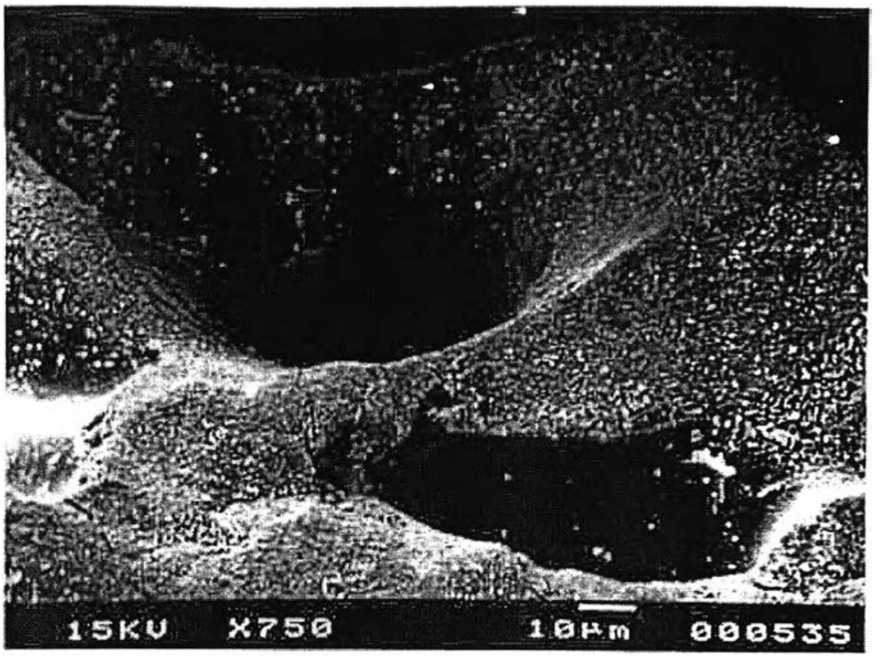

Figure B.6 External surface of carbon adsorbent from WH601

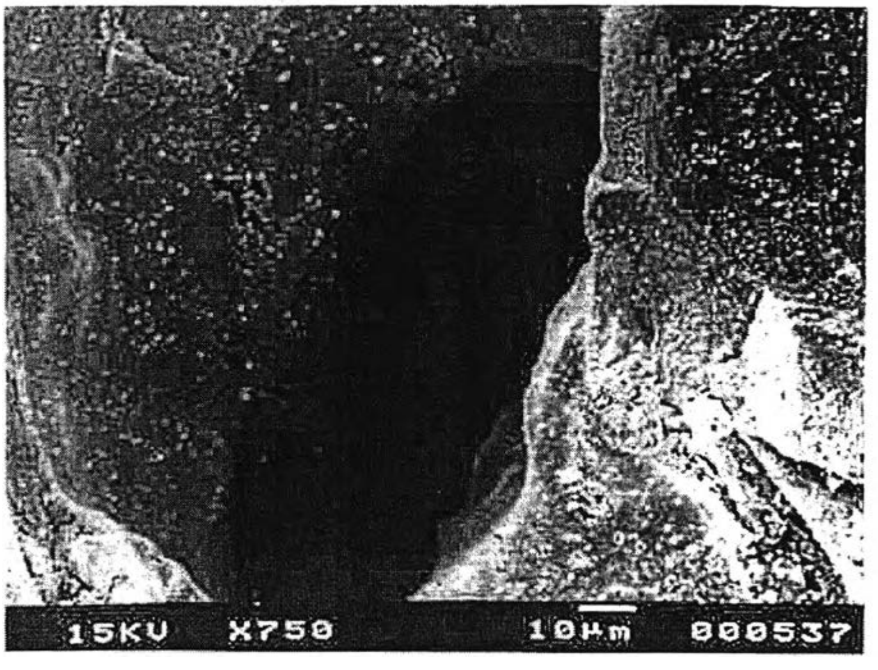

Figure B.7 External surface of carbon adsorbent from WH602

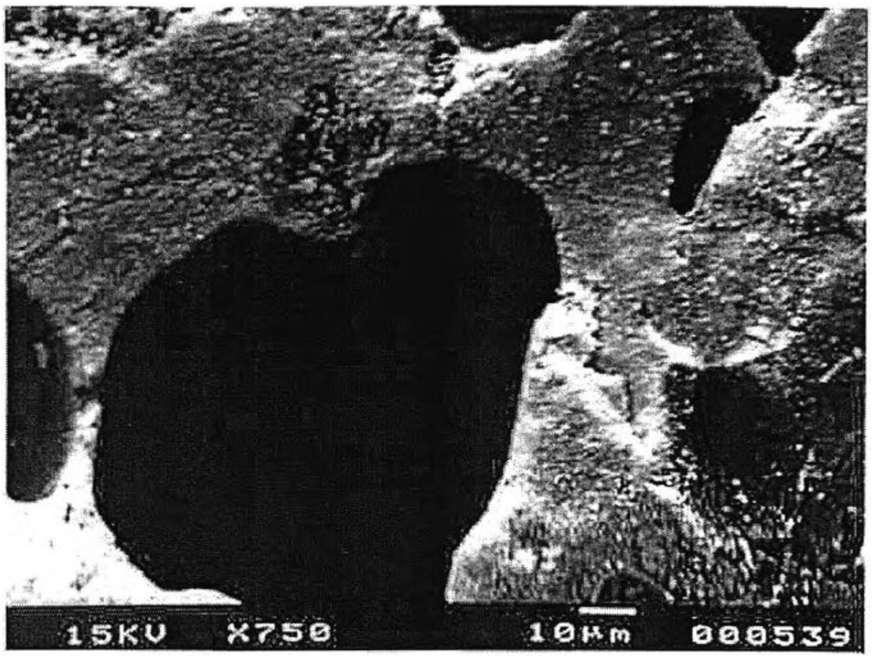

Figure B.8 External surface of carbon adsorbent from WH603

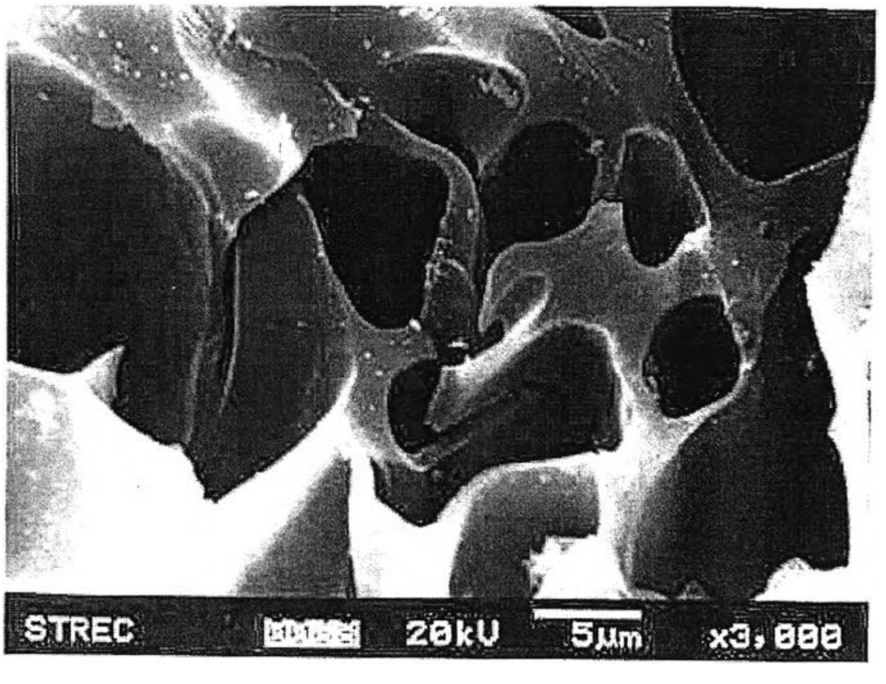

Figure B.9 External surface of carbon adsorbent from RH402

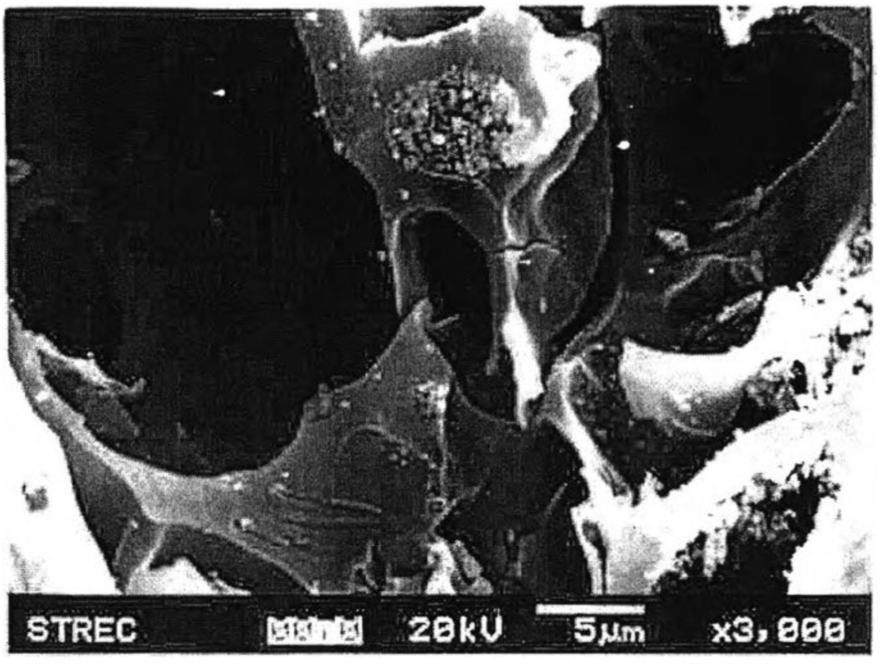

Figure B.10 External surface of carbon adsorbent from RH403

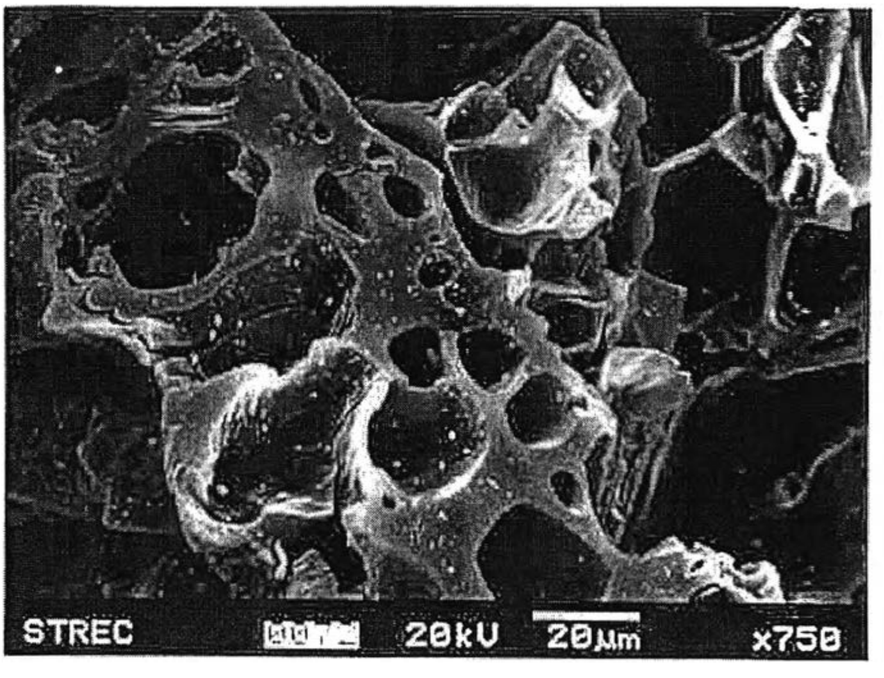

Figure B.11 External surface of carbon adsorbent from RH501

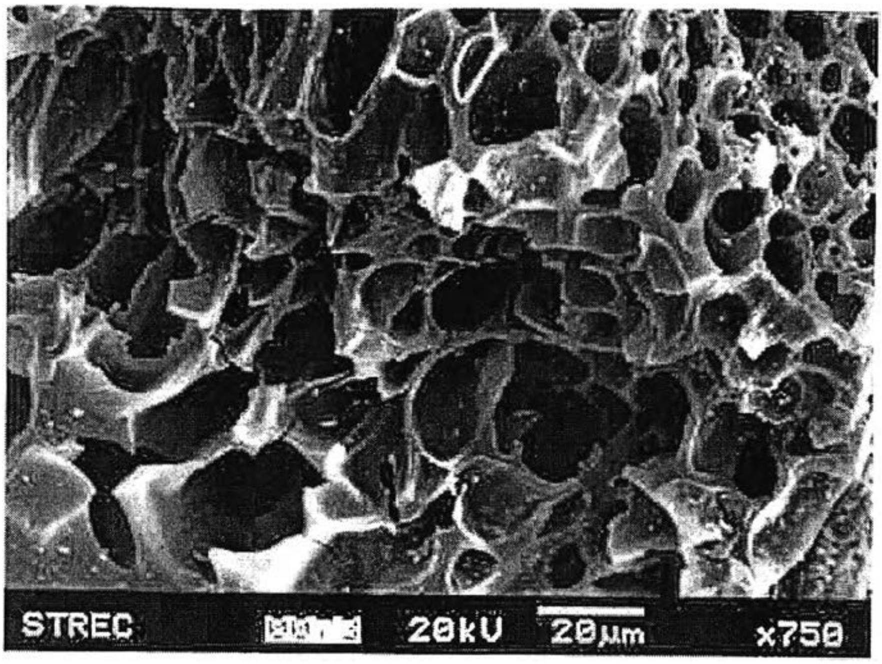

Figure B.12 External surface of carbon adsorbent from RH502

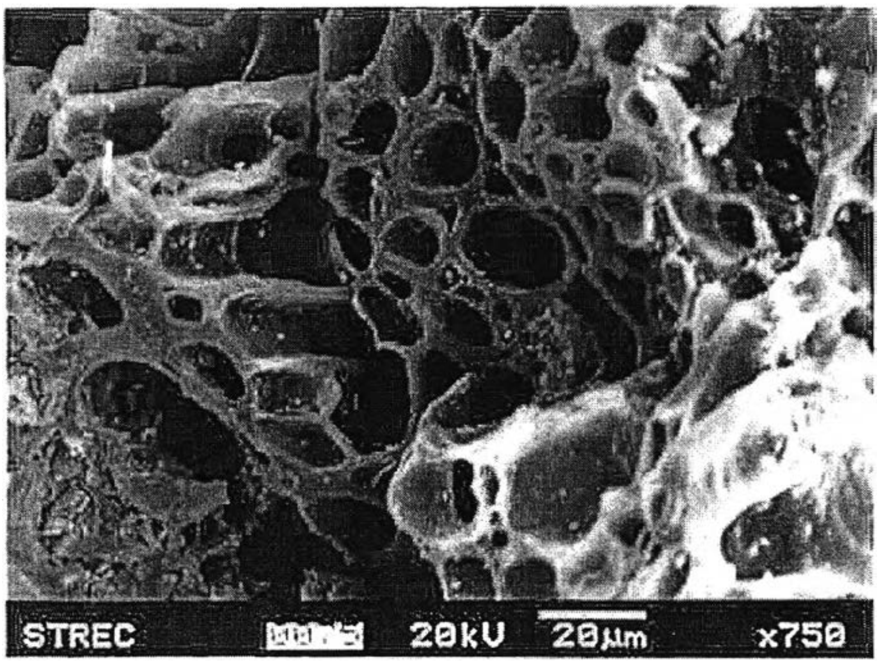

Figure B.13 External surface of carbon adsorbent from RH503

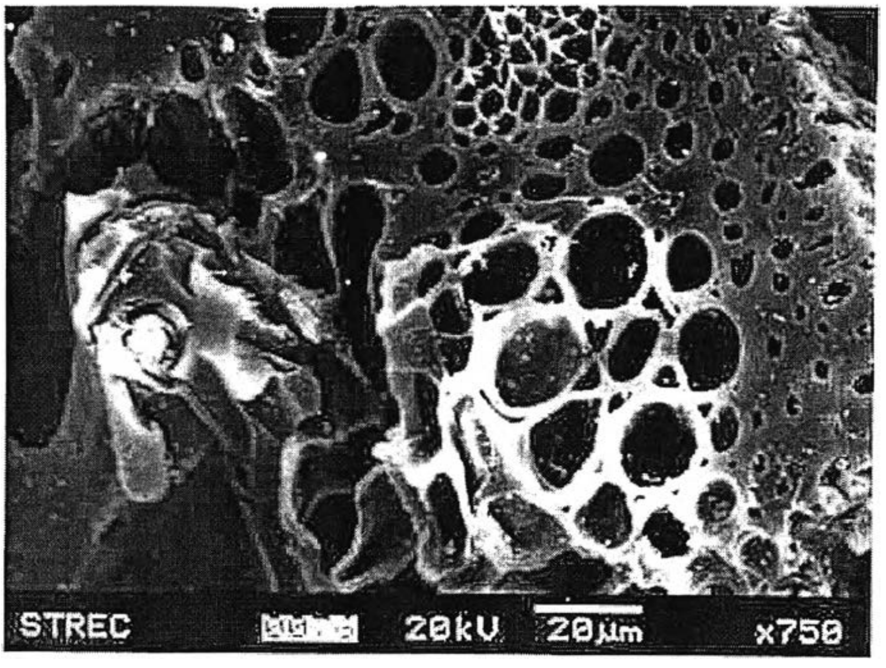

Figure B.14 External surface of carbon adsorbent from RH601

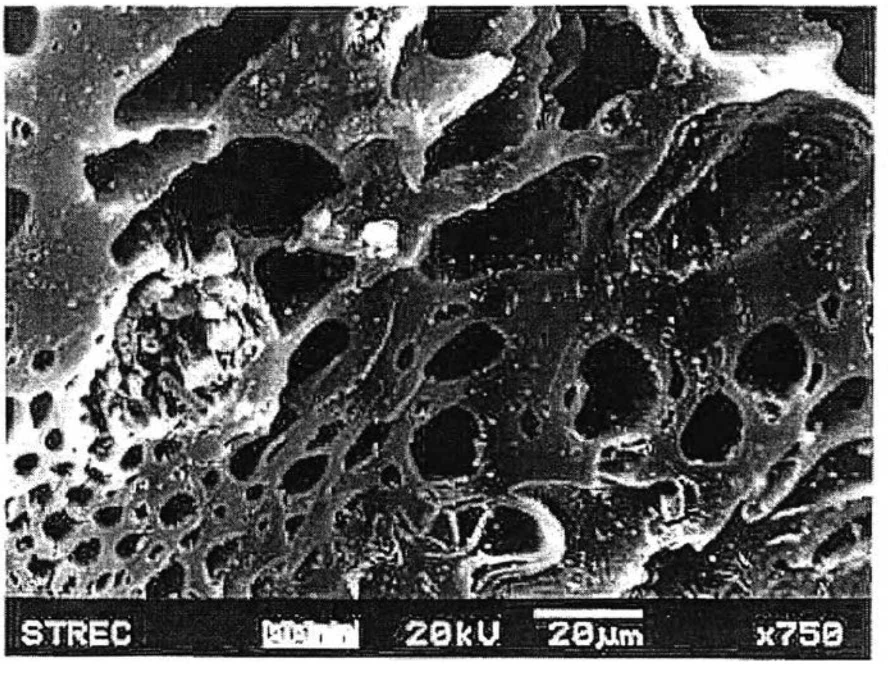

Figure B.15 External surface of carbon adsorbent from RH602

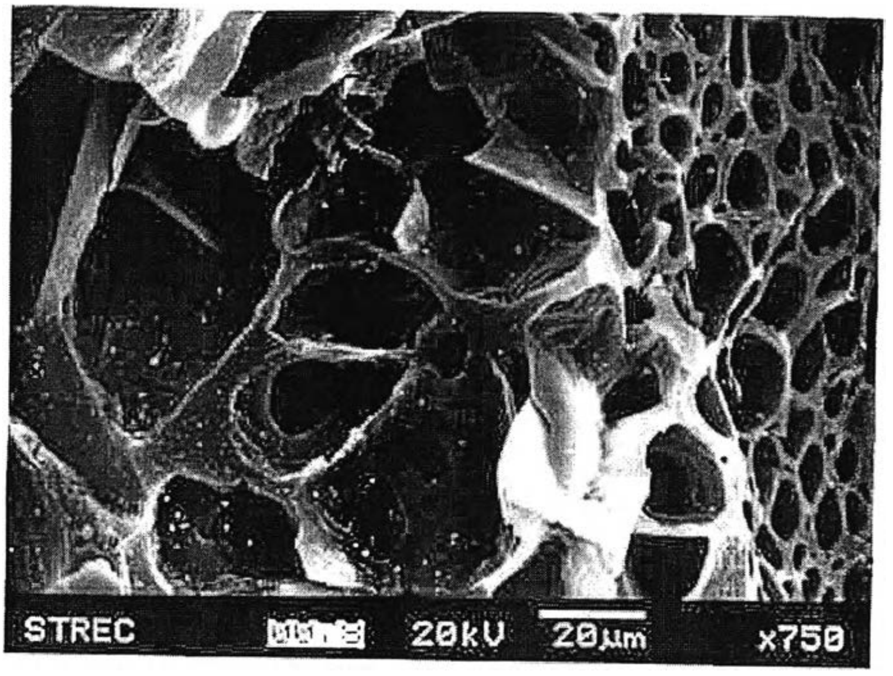

Figure B.16 External surface of carbon adsorbent from RH603

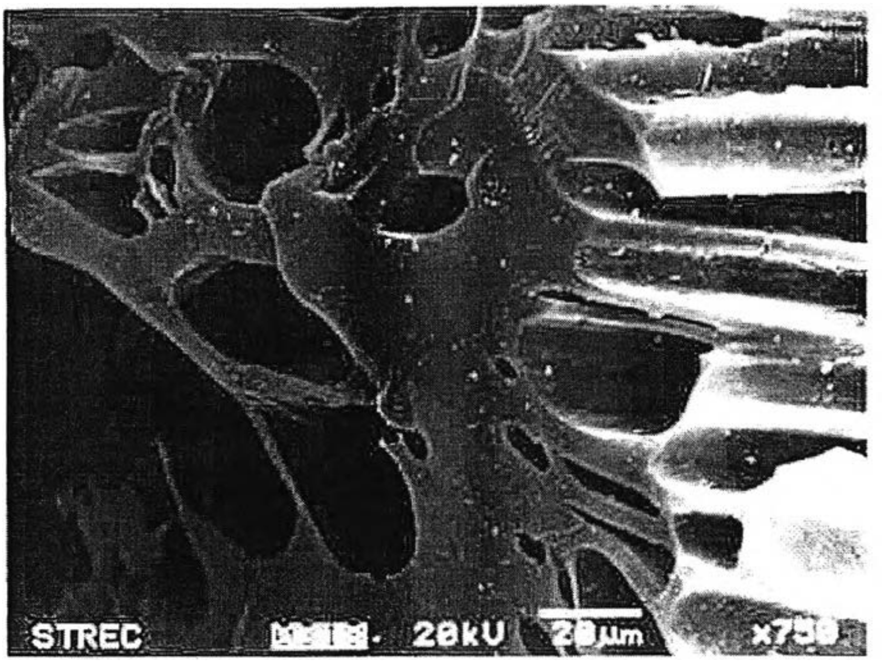

Figure B.17 External surface of carbon adsorbent from SCB402

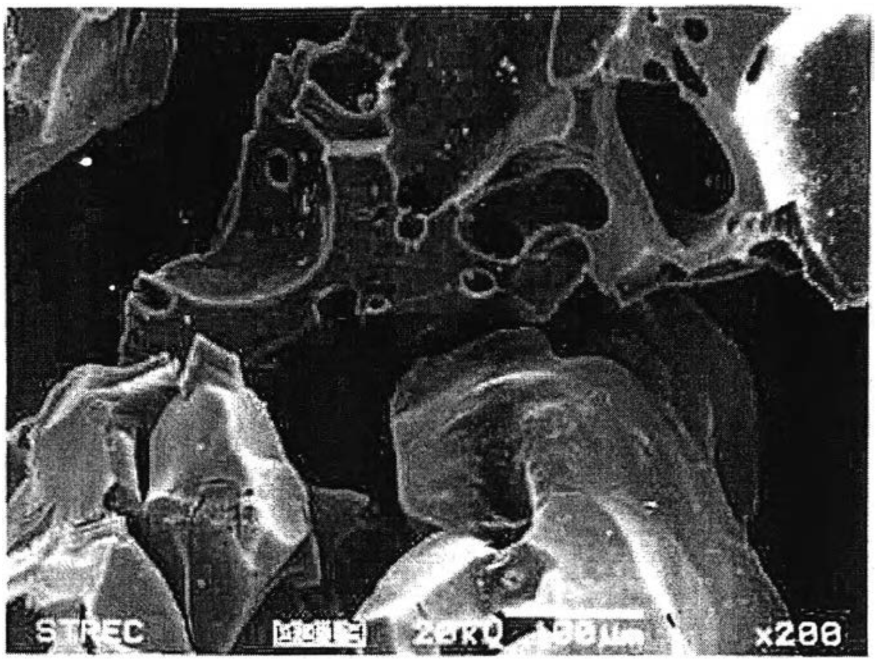

Figure B.18 External surface of carbon adsorbent from SCB403

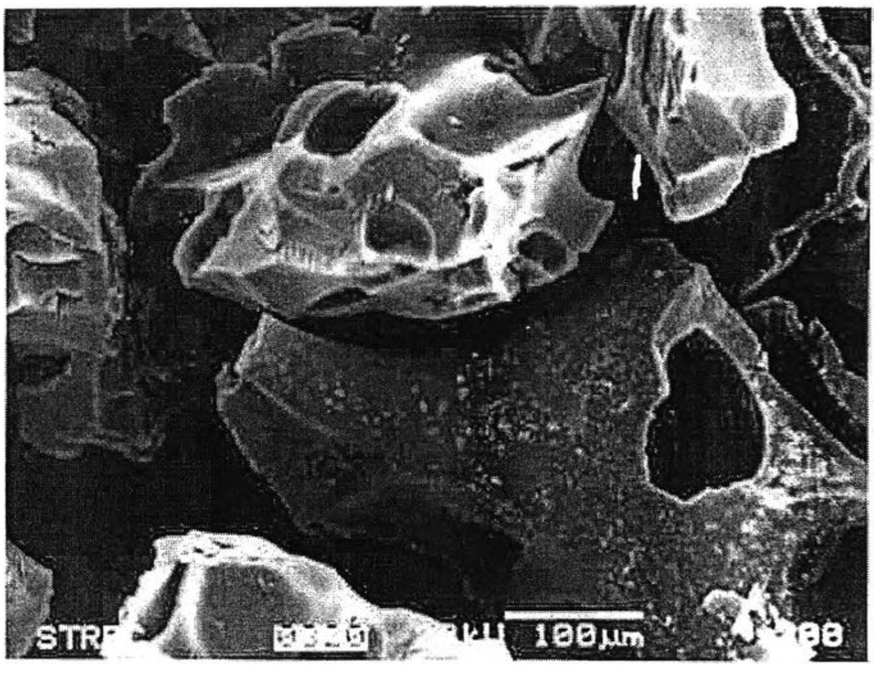

Figure B.19 External surface of carbon adsorbent from SCB501

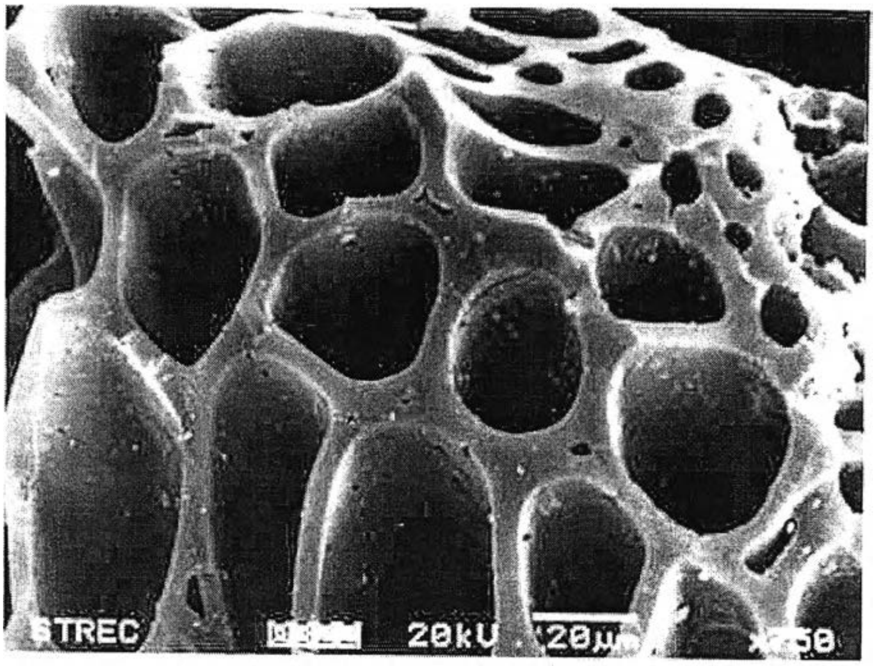

Figure B.20 External surface of carbon adsorbent from SCB502

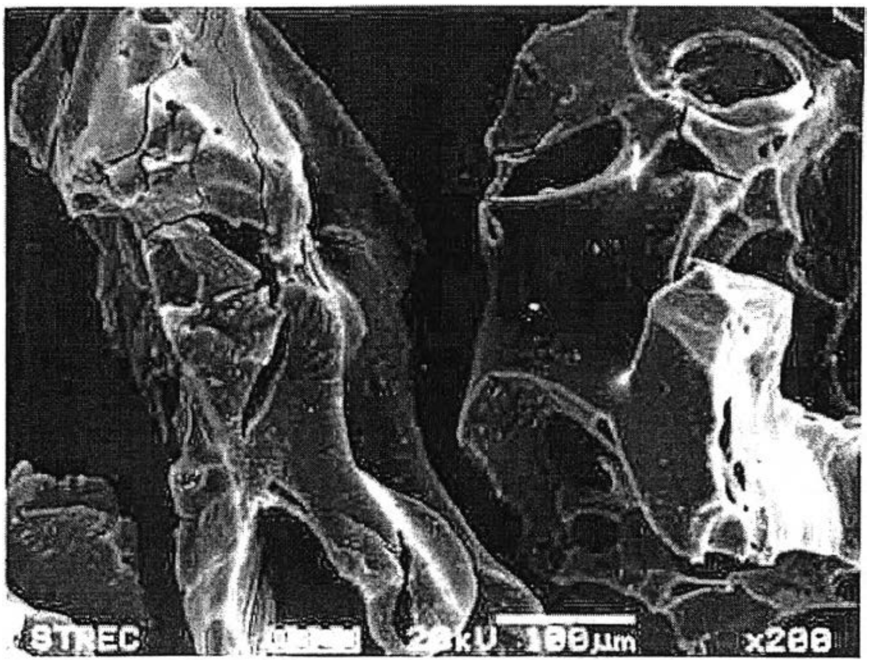

Figure B.21 External surface of carbon adsorbent from SCB503

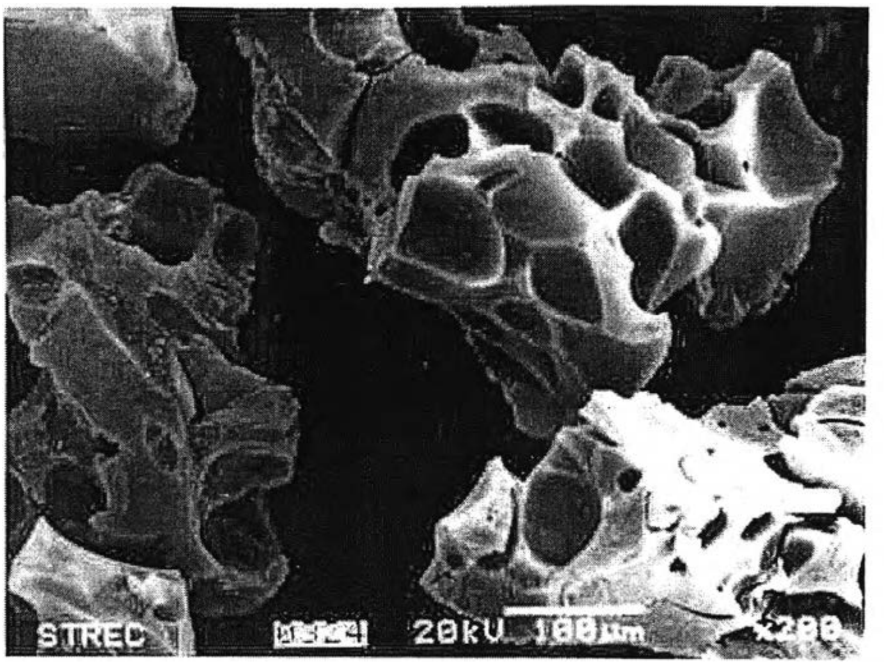

Figure B.22 External surface of carbon adsorbent from SCB601

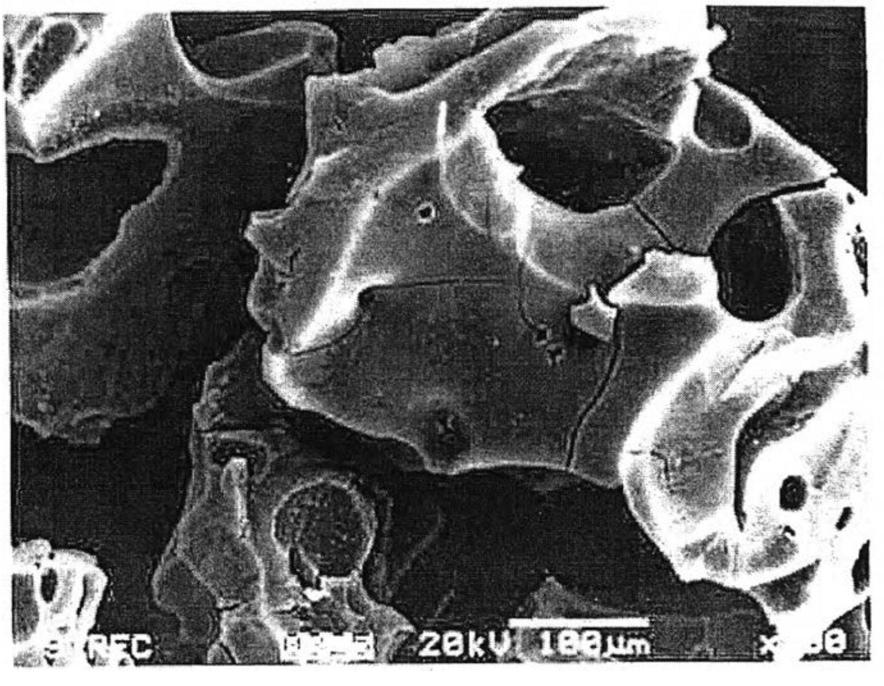

Figure B.23 External surface of carbon adsorbent from SCB602

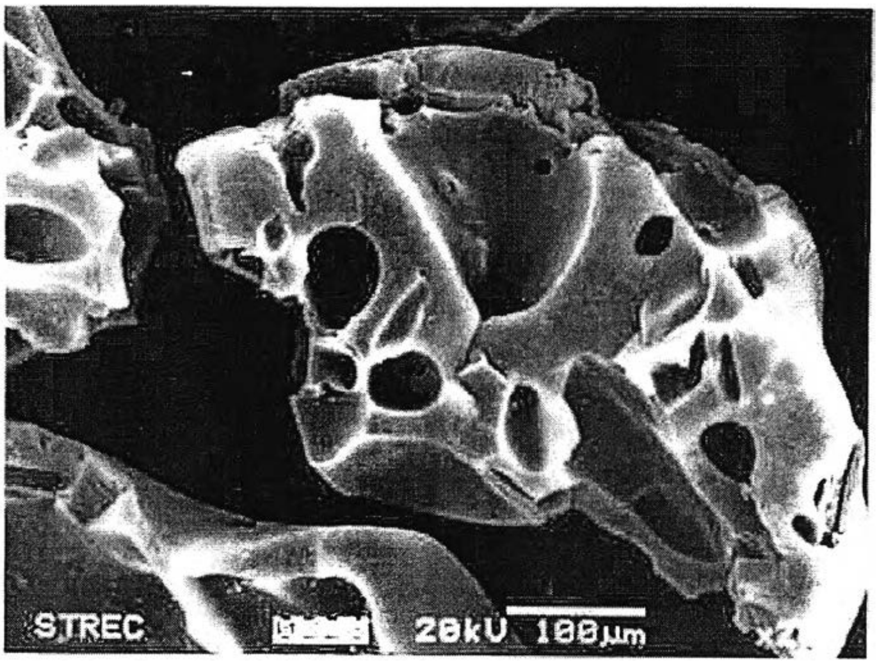

Figure B.24 External surface of carbon adsorbent from SCB603

APPENDIX C

EXPERIMENTAL DATA

Table C.1 The retention times and variances of benzene vapour on WH401

T (°C)	Q (cm^3/min)	t_R (sec)	σ^2 (sec^2)	T (°C)	Q (cm^3/min)	t_R (sec)	σ^2 (sec^2)
180	37.937	449.55	37,732.47	210	37.937	148.22	9,938.76
	46.601	346.85	26,542.23		46.601	122.26	6,654.67
	55.265	331.57	27,450.04		55.265	92.18	5,108.05
	63.929	256.64	18,609.40		63.929	79.05	4,346.41
	72.593	217.51	19,418.78		72.593	84.09	3,927.85
190	29.273	504.07	103,162.41	220	20.609	214.29	16,111.98
	37.937	359.89	53,375.28		29.273	100.78	4,705.15
	46.601	277.18	37,025.83		37.937	130.20	7,959.21
	55.265	340.75	52,070.44		46.601	71.05	2,731.62
	63.929	181.05	19,457.66		55.265	62.59	2,296.36
					63.929	55.21	1,918.48
200	29.273	309.62	49,263.89	230	20.609	119.49	5,113.25
	37.937	234.31	27,489.79		29.273	97.73	3,833.98
	46.601	277.36	25,885.23		37.937	60.33	1,731.87
	55.265	166.46	16,257.70		46.601	52.56	1,558.85
	63.929	149.02	13,538.48		55.265	47.53	1,248.27
	72.593	143.54	12,263.19		63.929	38.03	917.89

Table C.2 The retention times and variances of benzene vapour on WH402

T (°C)	Q (cm^3/min)	t_R (sec)	σ^2 (sec^2)	T (°C)	Q (cm^3/min)	t_R (sec)	σ^2 (sec^2)
180	20.609	716.29	74,989.38	210	20.609	219.47	7,050.73
	29.273	677.17	67,184.32		29.273	163.32	4,339.66
	37.937	427.37	29,954.59		37.937	130.36	3,142.21
	46.601	303.01	17,373.05		46.601	120.03	2,552.67
	55.265	264.40	13,944.39		55.265	88.52	1,728.56
	63.929	242.49	12,243.88		63.929	74.72	1,328.00
190	20.609	471.24	38,047.78	220	20.609	145.33	3,185.16
	29.273	423.91	27,201.07		29.273	136.86	2,801.00
	37.937	349.79	20,411.88		37.937	87.52	1,385.32
	46.601	229.02	9,793.31		46.601	65.16	846.83
	55.265	192.18	7,566.36		55.265	60.67	802.95
	63.929	150.03	5,364.75		63.929	54.96	672.66
200	20.609	360.79	18,354.10	230	20.609	123.95	2,145.26
	29.273	233.27	9,529.55		29.273	97.11	1,354.90
	37.937	182.76	6,161.89		37.937	70.89	810.86
	46.601	139.04	4,151.13		46.601	58.27	601.73
	55.265	112.44	2,894.49		55.265	44.10	404.73
	63.929	122.18	3,045.05		63.929	35.24	306.56

Table C.3 The retention times and variances of benzene vapour on WH403

T (°C)	Q (cm^3/min)	t_R (sec)	σ^2 (sec^2)	T (°C)	Q (cm^3/min)	t_R (sec)	σ^2 (sec^2)
180	29.273	295.27	15,986.65	210	20.609	214.88	9,536.07
	37.937	170.11	65,277.33		29.273	184.35	7,020.86
	46.601	139.47	4,733.63		37.937	122.60	3,588.73
	55.265	126.76	4,127.33		46.601	104.36	2,881.71
					55.265	96.23	2,391.74
					63.929	73.42	1,537.81
190	37.937	222.07	11,699.61	220	20.609	140.22	3,589.79
	46.601	193.21	8,571.65		29.273	94.26	1,828.66
	55.265	142.16	5,492.92		37.937	69.93	1,158.51
	63.929	133.50	4,653.20		46.601	54.04	680.74
					55.265	49.81	629.78
					63.929	40.95	474.51
200	20.609	327.88	23,180.75	230	20.609	94.92	1,497.99
	29.273	224.29	10,798.46		29.273	72.07	1,001.65
	37.937	190.87	8,768.32		37.937	49.03	513.39
	46.601	164.36	6,545.35		46.601	41.00	373.98
	55.265	136.17	4,758.21		55.265	32.67	295.21
	63.929	123.13	3,882.98		63.929	28.00	197.56

Table C.4 The retention times and variances of benzene vapour on WH501

T (°C)	Q (cm^3/min)	t_R (sec)	σ^2 (sec^2)	T (°C)	Q (cm^3/min)	t_R (sec)	σ^2 (sec^2)
170	20.609	348.27	46,677.07	210	20.609	73.33	1,567.40
	29.273	250.65	24,551.16		29.273	60.07	1,045.21
	37.937	174.68	13,029.25		37.937	46.46	658.31
	46.601	147.05	9,239.08		46.601	32.12	337.87
	55.265	126.18	7,266.42		55.265	27.98	227.27
	63.929	97.80	4,821.94		63.929	24.52	210.54
180	20.609	223.42	17,681.48	220	20.609	61.38	877.37
	29.273	160.45	9,591.21		29.273	44.96	514.49
	37.937	189.02	11,632.06		37.937	29.28	243.01
	46.601	111.72	5,214.16		46.601	28.14	228.79
	55.265	78.71	2,845.51		55.265	19.16	114.45
	63.929	67.25	2,159.35		63.929	18.60	107.85
190	20.609	212.85	14,847.83	230	20.609	53.29	561.04
	29.273	108.00	4,123.86		29.273	29.01	179.69
	37.937	88.04	2,953.08		37.937	21.42	108.14
	46.601	62.92	1,551.34		46.601	20.86	106.24
	55.265	56.96	1,369.05		55.265	17.02	69.66
	63.929	53.18	1,250.20		63.929	13.25	49.56
200	20.609	103.23	3,231.08				
	29.273	74.72	1,792.70				
	37.937	62.89	1,329.33				
	46.601	47.55	850.15				
	55.265	38.07	537.62				
	63.929	32.49	429.46				

Table C.5 The retention times and variances of benzene vapour on WH502

T (°C)	Q (cm^3/min)	t_R (sec)	σ^2 (sec^2)	T (°C)	Q (cm^3/min)	t_R (sec)	σ^2 (sec^2)
180	20.609	751.05	112,550.09	210	20.609	234.87	9,204.01
	29.273	455.31	45,800.15		29.273	154.52	4,254.17
	37.937	385.57	37,371.58		37.937	131.85	3,440.18
	46.601	295.34	22,662.57		46.601	95.92	2,048.78
	55.265	240.15	16,357.21		55.265	89.96	1,895.45
	63.929	230.40	15,163.97		63.929	66.40	1,125.35
190	20.609	551.77	57,077.12	220	20.609	164.69	4,584.57
	29.273	300.22	18,937.53		29.273	104.30	1,867.34
	37.937	281.49	16,507.15		37.937	77.73	1,152.38
	46.601	182.47	8,277.93		46.601	61.53	844.97
	55.265	199.94	8,683.49		55.265	54.03	665.12
	63.929	165.84	6,811.15		63.929	47.84	563.34
200	20.609	482.92	42,682.13	230	20.609	137.43	2,815.91
	29.273	258.50	13,956.56		29.273	72.61	903.52
	37.937	218.81	10,276.77		37.937	60.16	627.89
	46.601	177.65	7,955.22		46.601	44.30	423.58
	55.265	150.98	5,767.00		55.265	41.70	334.23
	63.929	123.96	4,206.70		63.929	37.94	311.03

Table C.6 The retention times and variances of bezene vapour on WH503

T (°C)	Q (cm^3/min)	t_R (sec)	σ^2 (sec^2)	T (°C)	Q (cm^3/min)	t_R (sec)	σ^2 (sec^2)
180	29.273	479.69	38,352.58	210	29.273	158.39	12,115.72
	37.937	449.55	37,732.47		37.937	148.22	9,938.76
	46.601	346.85	26,542.23		46.601	112.26	6,654.67
	55.265	331.57	27,450.04		55.265	92.18	5,108.05
	63.929	256.64	18,609.40		63.929	79.05	4,346.41
	72.593	217.51	19,418.78		72.593	84.08	3,927.95
190	29.273	504.07	103,162.41	220	20.609	214.29	16,111.98
	37.937	359.89	53,375.28		29.273	100.78	4,705.15
	46.601	277.18	37,025.83		37.937	130.20	7,959.21
	55.265	340.75	52,070.44		46.601	71.05	2,731.62
	63.929	181.05	19,457.66		55.265	62.59	2,296.36
					63.929	55.31	1,918.43
200	29.273	309.62	49,623.89	230	20.609	119.49	5,113.25
	37.937	234.31	27,489.79		29.273	97.73	3,833.98
	46.601	227.36	25,885.23		37.937	60.33	1,731.87
	55.265	166.46	16,257.70		46.601	52.56	1,558.85
	63.929	149.02	13,538.48		55.265	47.53	1,248.27
	72.593	143.54	12,263.19		63.929	38.03	917.89

Table C.7 The retention times and variances of bezene vapour on WH601

T (°C)	Q (cm^3/min)	t_R (sec)	σ^2 (sec^2)	T (°C)	Q (cm^3/min)	t_R (sec)	σ^2 (sec^2)
180	29.273	870.10	234,780.56	210	29.273	229.25	12,443.69
	37.937	498.84	68,912.84		37.937	159.35	8,747.36
	46.601	473.77	67,002.99		46.601	159.71	6,368.94
	55.265	343.52	36,792.64		55.265	130.15	4,329.69
	63.929	329.58	32,639.82		63.929	110.46	3,164.32
	72.593	284.37	25,790.90		72.593	80.31	1,648.05
190	29.273	376.04	39,862.93	220	29.273	113.60	2,862.99
	37.937	301.24	24,442.41		37.937	88.89	1,770.19
	46.601	248.48	17,488.90		46.601	77.55	1,490.54
	55.265	210.39	13,669.26		55.265	71.92	1,255.73
	63.929	189.27	9,612.34		63.929	60.81	831.36
	72.593	177.68	9,063.95		72.593	53.09	670.01
200	29.273	275.27	17,999.69	230	29.273	104.34	1,962.60
	37.937	251.94	14,819.87		37.937	72.51	1,040.86
	46.601	186.60	9,042.75		46.601	58.33	740.96
	55.265	147.80	6,038.22		55.265	47.85	545.39
	63.929	143.57	5,518.96		63.929	42.58	394.56
	72.593	117.34	3,798.03		72.593	40.18	346.13

Table C.8 The retention times and variances of bezene vapour on WH602

T (°C)	Q (cm^3/min)	t_R (sec)	σ^2 (sec^2)	T (°C)	Q (cm^3/min)	t_R (sec)	σ^2 (sec^2)
180	29.273	845.17	242,809.37	210	29.273	239.37	16,204.64
	37.937	585.00	106,711.66		37.937	170.18	9,279.50
	46.601	506.62	84,751.85		46.601	132.66	5,033.53
	55.265	437.36	62,356.30		55.265	124.40	4,642.09
	63.929	355.36	47,618.62		63.929	105.43	3,812.76
	72.593	292.76	29,764.22		72.593	93.51	2,653.51
190	29.273	511.94	82,650.70	220	29.273	173.91	7,906.03
	37.937	394.91	50,749.59		37.937	148.65	5,549.94
	46.601	326.18	31,950.29		46.601	98.39	2,626.47
	55.265	246.11	19,670.90		55.265	87.68	2,216.98
	63.929	218.90	16,651.51		63.929	70.70	1,379.89
	72.593	213.37	15,697.70		72.593	67.21	1,181.11
200	29.273	315.98	30,323.93	230	29.273	121.97	3,375.16
	37.937	254.66	19,754.93		37.937	80.50	1,561.13
	46.601	201.07	12,695.12		46.601	60.97	1,022.24
	55.265	170.55	8,728.13		55.265	53.43	740.50
	63.929	143.87	6,549.16		63.929	46.92	574.52
	72.593	133.37	5,820.83		72.593	44.17	505.62

Table C.9 The retention times and variances of bezene vapour on WH603

T (°C)	Q (cm^3/min)	t_R (sec)	σ^2 (sec^2)	T (°C)	Q (cm^3/min)	t_R (sec)	σ^2 (sec^2)
180	29.273	515.69	155,383.88	210	29.273	144.90	9,724.35
	37.937	409.46	102,268.88		37.937	90.60	4,240.03
	46.601	302.28	54,052.02		46.601	81.47	3,284.57
	55.265	263.05	41,599.88		55.265	69.77	2,601.60
	63.929	199.98	25,877.08		63.929	60.12	1,908.80
	72.593	181.71	20,090.35		72.593	51.46	1,644.73
190	29.273	346.63	58,565.00	220	29.273	105.10	4,614.29
	37.937	252.67	36,164.40		37.937	85.08	3,196.42
	46.601	218.20	26,713.07		46.601	64.57	2,029.11
	55.265	162.97	15,854.03		55.265	47.51	1,040.17
	63.929	134.75	10,238.05		63.929	41.63	879.60
	72.593	111.12	7,880.64		72.593	38.31	728.71
200	29.273	214.38	23,483.07	230	29.273	88.30	3,067.74
	37.937	152.04	11,353.19		37.937	66.14	1,832.67
	46.601	120.32	7,506.37		46.601	51.92	1,243.47
	55.265	102.80	5,967.23		55.265	43.30	867.75
	63.929	96.54	6,090.70		63.929	36.06	653.75
	72.593	84.15	3,841.19		72.593	31.90	554.71

Table C.10 The retention times and variances of toluene vapour on WH401

T (°C)	Q (cm^3/min)	t_R (sec)	σ^2 (sec^2)	T (°C)	Q (cm^3/min)	t_R (sec)	σ^2 (sec^2)
180	37.937	617.27	140,409.49	210	20.609	287.36	37,021.44
	46.601	502.35	112,840.82		29.273	212.45	34,967.03
	55.265	420.97	82,851.64		37.937	156.66	12,980.67
	63.929	375.39	81,907.30		46.601	133.64	15,252.85
	72.593	359.69	84,593.79		55.265	100.54	7,292.45
	81.257	302.55	55,964.34		63.929	95.70	7,540.37
	89.921	268.63	40,341.62		72.593	81.14	5,072.20
190	46.601	335.91	80,297.59	220	20.609	173.38	13,726.82
	55.265	252.70	34,042.38		29.273	153.25	16,362.07
	63.929	229.86	33,929.69		37.937	106.71	6,230.33
	72.593	199.91	25,847.76		46.601	89.30	5,264.80
	81.257	189.92	29,528.12		55.265	72.16	5,568.01
	89.921	161.28	16,809.19		63.929	60.49	3,158.40
					72.593	54.26	2,699.92
					81.257	55.05	3,258.62
					89.921	46.86	2,172.73
200	20.609	373.20	52,529.70	230	20.609	134.74	12,047.00
	29.273	275.27	33,360.52		29.273	91.01	4,164.89
	37.937	222.29	29,958.88		37.937	61.24	2,427.80
	46.601	164.69	14,315.58		46.601	54.99	2,031.88
	55.265	130.40	9,791.30		55.265	43.37	1,445.23
	63.929	115.92	8,942.44		63.929	42.06	1,583.51
	72.593	106.70	7,591.24		72.593	37.78	1,237.02
	81.257	99.56	7,177.63		81.257	34.35	1,363.87
	89.921	91.90	6,647.86		89.921	26.97	759.81

Table C.11 The retention times and variances of toluene vapour on WH402

T (°C)	Q (cm^3/min)	t_R (sec)	σ^2 (sec^2)	T (°C)	Q (cm^3/min)	t_R (sec)	σ^2 (sec^2)
180	46.601	543.51	90,639.07	210	37.937	221.86	16,711.76
	55.265	467.33	76,299.44		46.601	160.75	7,140.23
	63.929	365.11	50,438.59		55.265	145.07	6,957.17
	72.593	328.85	40,327.79		63.929	122.33	5,513.09
	81.257	302.61	35,211.46		72.593	112.35	4,338.75
	89.921	275.22	28,916.22		81.257	103.71	4,036.01
190	46.601	462.17	157,709.23	220	20.609	181.74	9,615.06
	55.265	247.55	24,265.47		29.273	151.36	6,283.58
	63.929	334.15	42,975.61		37.937	122.94	4,365.91
	72.593	288.42	31,861.42		46.601	78.36	1,864.90
	81.257	271.34	29,823.69		55.265	62.50	1,402.29
	89.921	247.62	26,590.61		63.929	54.22	1,086.20
200	37.937	257.49	18,325.51	230	20.609	150.63	6,055.95
	46.601	115.57	3,827.05		29.273	96.12	2,685.49
	55.265	210.32	15,451.98		37.937	80.13	1,846.37
	63.929	177.71	10,527.63		46.601	62.08	1,268.89
	72.593	169.46	10,316.21		55.265	52.79	956.25
	81.257	146.32	8,367.30		63.929	46.95	806.11

Table C.12 The retention times and variances of toluene vapour on WH403

T (°C)	Q (cm^3/min)	t_R (sec)	σ^2 (sec^2)	T (°C)	Q (cm^3/min)	t_R (sec)	σ^2 (sec^2)
180	46.601	1195.32	335,963.54	210	37.937	384.54	49,749.34
	55.265	946.22	225,374.49		46.601	268.97	19,905.06
	63.929	895.02	308,174.72		55.265	224.53	16,021.93
	72.593	814.61	254,317.28		63.929	201.53	11,713.53
	81.257	679.60	128,163.49		72.593	181.21	9,786.16
	89.921	628.02	119,934.62		81.257	161.45	9,450.12
190	46.601	676.52	130,394.20	220	20.609	422.34	42,023.09
	55.265	590.56	103,711.01		29.273	288.74	19,515.04,
	63.929	546.14	105,209.41		37.937	238.77	15,053.24
	72.593	456.47	58,358.76		46.601	178.43	9,005.43
	81.257	394.14	47,238.87		55.265	157.49	7,419.25
	89.921	376.30	42,341.51		63.929	133.20	4,990.55
200	37.937	530.02	87,730,72	230	20.609	208.85	9,959.11
	46.601	350.54	37,936.20		29.273	149.88	5,368.21
	55.265	335.44	32,419.89		37.937	141.50	4,961.31
	63.929	279.63	21,651.86		46.601	101.01	2,717.38
	72.593	210.33	14,211.82		55.265	93.67	2,514.33
	81.257	228.89	16,765.38		63.929	76.44	1,779.11
					72.593	72.64	1,705.18

Table C.13 The retention times and variances of tpluene vapour on WH501

T (°C)	Q (cm^3/min)	t_R (sec)	σ^2 (sec^2)	T (°C)	Q (cm^3/min)	t_R (sec)	σ^2 (sec^2)
180	46.601	546.25	113,484.55	210	37.937	178.12	14,379.17
	55.265	428.50	112,451.56		46.601	135.87	8,326.42
	63.929	424.57	99,268.50		55.265	111.99	6,036.56
	72.593	364.59	69,433.89		63.929	96.68	4,652.31
	81.257	307.13	52,237.02		72.593	90.35	3,892.97
	89.921	281.17	45,704.87		81.257	79.07	3,383.10
190	46.601	330.44	52,440.62	220	20.609	288.92	45,312.51
	55.265	271.54	37,237.31		29.273	219.74	19,013.79
	63.929	253.48	31,742.54		37.937	168.15	13,327.99
	72.593	247.11	30,905.73		46.601	128.63	8,232.71
	81.257	211.20	23,050.79		55.265	111.13	6,057.12
	89.921	183.39	18,285.29		63.929	94.27	4,490.26
200	37.937	207.99	19,193.12	230	20.609	206.87	16,287.07
	46.601	135.09	8,540.24		29.273	133.13	7,567.93
	55.265	115.08	6,865.94		37.937	108.04	4,714.39
	63.929	113.72	6,114.36		46.601	86.67	3,392.52
	72.593	96.06	4,740.72		55.265	68.67	2,092.36
	81.257	91.86	4,375.48		63.929	62.51	1,765.07

Table C.14 The retention times and variances of toluene vapour on WH502

T (°C)	Q (cm^3/min)	t_R (sec)	σ^2 (sec^2)	T (°C)	Q (cm^3/min)	t_R (sec)	σ^2 (sec^2)
190	46.601	832.00	91,768.91	220	20.609	481.27	26,470.47
	55.265	779.76	95,318.11		29.273	363.54	19,239.84
	63.929	564.95	63,909.80		37.937	273.48	10,886.19
	72.593	510.56	37,545.68		46.601	214.55	6,810.30
	81.257	479.06	47,821.02		55.265	181.00	5,610.45
	89.921	448.24	38,687.43		63.929	156.21	3,931.06
200	37.937	642.19	65,241.81	230	20.609	308.85	13,306.11
	46.601	573.70	55,529.73		29.273	214.55	6,733.81
	55.265	572.95	52,338.27		37.937	149.81	3,225.92
	63.929	547.49	48,875.04		46.601	137.98	2,588.13
	72.593	453.15	38,912.17		55.265	104.35	1,724.14
	81.257	440.98	36,976.11		63.929	100.57	1,538.46
210	29.273	485.71	39,276.79	240	20.609	215.77	5,975.63
	37.937	410.68	26,520.38		29.273	153.55	3,385.51
	46.601	280.11	13,103.72		37.937	101.21	1,513.79
	55.265	250.27	12,410.30		46.601	91.24	1,108.98
	63.929	226.96	8,832.75		55.265	76.25	879.87
	72.593	218.93	8,164.93		63.929	65.75	654.00

Table C.15 The retention times and variances of toluene vapour on WH503

T (°C)	Q (cm^3/min)	t_R (sec)	σ^2 (sec^2)	T (°C)	Q (cm^3/min)	t_R (sec)	σ^2 (sec^2)
180	46.601	760.83	188,929.04	210	20.609	373.65	41,658.88
	55.265	585.93	151,882.25		29.273	318.50	34,885.84
	63.929	553.84	134,000.87		37.937	214.16	16,112.43
	72.593	453.22	94,030.49		46.601	185.66	12,868.47
	81.257	409.75	72,677.87		55.265	143.17	8,455.26
	89.921	378.23	64,269.72		63.929	132.58	7,364.04
190	37.937	531.96	106,034.07	220	20.609	289.22	23,260.61
	46.601	456.62	93,635.33		29.273	168.75	9,778.19
	55.265	370.67	53,964.74		37.937	158.20	8,448.90
	63.929	438.26	81,214.10		46.601	123.90	5,760.69
	72.593	456.86	87,121.64		55.265	104.19	3,997.74
	81.257	381.73	65,599.75		63.929	87.18	2,961.55
200	29.273	474.52	70,528.88	230	20.609	179.55	9,662.73
	37.937	366.54	50,777.20		29.273	129.21	5,135.16
	46.601	266.92	27,491.30		37.937	102.86	3,415.24
	55.265	247.85	26,703.68		46.601	79.25	2,114.00
	63.929	214.67	20,703.51		55.265	68.13	1,615.72
	72.593	190.66	16,781.83		63.929	56.85	1,221.16
	81.257	179.97	12,936.39				

Table C.16 The retention times and variances of toluene vapour on WH601

T (°C)	Q (cm^3/min)	t_R (sec)	σ^2 (sec^2)	T (°C)	Q (cm^3/min)	t_R (sec)	σ^2 (sec^2)
200	55.265	849.04	200,676.13	230	29.273	335.10	27,401.83
	63.929	729.83	154,521.19		37.937	256.03	20,121.28
	72.593	643.00	118,724.11		46.601	181.13	10,519.53
	81.257	585.74	114,937.13		55.265	169.26	9,406.53
	89.921	506.58	87,506.90		63.929	146.61	7,970.22
					72.593	130.29	7,368.43
210	37.937	670.39	122,143.33	240	37.937	200.61	9,998.52
	46.601	551.27	95,897.74		46.601	159.80	6,843.82
	55.265	486.09	68,715.46		55.265	130.21	4,771.35
	63.929	424.80	54,365.01		63.929	120.61	3,972.41
	72.593	390.66	55,988.26		72.593	102.09	3,286.16
	81.257	343.80	47,800.85		81.257	93.75	2,675.48
	89.921	325.25	41,038.11				
220	29.273	540.17	75,648.06	250	29.273	178.57	6,809.92
	37.937	413.32	52,190.60		37.937	134.66	4,445.80
	46.601	300.42	30,078.40		46.601	104.85	2,924.50
	55.265	273.89	28,746.38		55.265	94.70	2,346.44
	63.929	248.72	23,217.27		63.929	76.13	1,699.44
	72.593	212.28	18,458.62		72.593	69.88	1,505.96

Table C.17 The retention times and variances of toluene vapour on WH602

T (°C)	Q (cm^3/min)	t_R (sec)	σ^2 (sec^2)	T (°C)	Q (cm^3/min)	t_R (sec)	σ^2 (sec^2)
200	46.601	670.48	168,790.00	230	37.937	345.33	44,995.80
	55.265	642.42	161,362.32		46.601	287.59	33,642.19
	63.929	536.66	123,310.65		55.265	210.77	19,535.86
	72.593	505.64	140,513.68		63.929	208.14	19,903.66
	81.257	494.66	117,960.56		72.593	182.14	15,289.30
	89.921	429.16	92,905.16		81.257	157.97	12,100.93
210	46.601	513.33	126,504.67	240	29.273	196.57	14,542.61
	55.265	419.32	75,710.71		37.937	160.89	10,593.16
	63.929	345.58	60,286.18		46.601	121.77	5,649.73
	72.593	316.78	47,983.83		55.265	100.17	3,786.11
	81.257	283.67	40,595.92		63.929	89.23	3,521.96
	89.921	263.06	34,753.65		72.593	77.36	2,681.33
220	37.937	340.30	50,116.74	250	29.273	133.21	5,588.05
	46.601	307.90	41,100.85		37.937	102.91	3,655.93
	55.265	232.37	23,540.95		46.601	79.17	2,354.55
	63.929	225.61	26,722.37		55.265	70.59	2,046.59
	72.593	200.74	17,800.37		63.929	58.66	1,244.61
	81.257	174.87	13,465.44		72.593	52.64	1,175.74

Table C.18 The retention times and variances of toluene vapour on WH603

T (°C)	Q (cm^3/min)	t_R (sec)	σ^2 (sec^2)	T (°C)	Q (cm^3/min)	t_R (sec)	σ^2 (sec^2)
200	46.601	483.59	110,156.50	230	29.273	166.78	10,644.53
	55.265	451.51	84,054.39		37.937	100.85	3,455.07
	63.929	409.88	86,091.61		46.601	100.41	4,504.54
	72.593	376.83	70,613.91		55.265	93.54	3,446.54
	81.257	339.21	68,656.63		63.929	91.18	3,188.36
	89.921	318.82	64,559.94				
210	29.273	305.30	38,302.43	240	20.609	116.92	4,898.40
	37.937	263.77	27,096.21		29.273	105.39	3,820.68
	46.601	184.44	13,408.02		37.937	63.52	1,431.13
	55.265	174.42	12,367.49		46.601	58.60	1,141.74
	63.929	142.83	9,744.46		55.265	46.08	780.37
	72.593	123.67	6,838.94		63.929	44.36	722.04
220	29.273	207.81	14,979.55	250	20.609	99.45	2,894.72
	37.937	143.03	8,722.03		29.273	67.03	1,570.32
	46.601	140.01	8,166.74		37.937	69.71	1,440.68
	55.265	105.04	4,542.83		46.601	47.17	758.30
	63.929	100.41	4,159.24		55.265	42.37	617.08
	72.593	151.49	10,529.94		63.929	36.03	500.71

Table C.19 The retention times and variances of o-xylene vapour on WH401

T (°C)	Q (cm^3/min)	t_R (sec)	σ^2 (sec^2)	T (°C)	Q (cm^3/min)	t_R (sec)	σ^2 (sec^2)
230	63.929	3352.91	628,419.18	250	37.937	2006.02	106,164.01
	72.593	2828.71	417,490.46		46.601	1528.66	72,441.67
	81.257	2356.38	379,992.67		55.265	1447.18	77.212.05
	89.921	2372.21	334,624.88		63.929	1210.08	67,634.29
					72.593	1076.21	69,793.51
					81.257	1016.65	60,246.61
240	55.265	2333.41	285,173.91	260	46.601	1300.26	111,531.33
	63.929	1847.81	154,983.04		55.265	1118.50	72,046.32
	72.593	1668.03	170,856.16		63.929	1028.36	68,103.74
	81.257	1574.20	133,299.15		72.593	954.86	61,474.04
	89.921	1555.19	149,825.39		81.257	779.12	39,920.28
					89.921	673.18	37,150.76

Table C.20 The retention times and variances of o-xylene vapour on WH402

T (°C)	Q (cm^3/min)	t_R (sec)	σ^2 (sec^2)	T (°C)	Q (cm^3/min)	t_R (sec)	σ^2 (sec^2)
230	63.929	4912.06	558,522.13	250	55.265	2213.98	73,441.00
	72.593	4301.42	406,565.65		63.929	2055.06	73,709.04
	81.257	3792.42	374,321.03		72.593	1904.41	60,628.93
	89.921	3710.58	347,327.46		81.257	1533.11	44,015.69
					89.921	1390.47	45,387.71
240	55.265	3314.07	199,595.20	260	46.601	1773.75	39,510.48
	63.929	1739.99	148,687.11		55.265	1560.54	47,982.48
	72.593	2653.73	157,136.52		63.929	1268.24	30,393.94
	81.257	2225.32	116,442.80		72.593	1180.08	32,910.27
	89.921	2075.93	103,683.75		81.257	1143.44	33,234.97
					89.921	1002.48	28,931.32

Table C.21 The retention times and variances of o-xylene vapour on WH403

T (°C)	Q (cm^3/min)	t_R (sec)	σ^2 (sec^2)	T (°C)	Q (cm^3/min)	t_R (sec)	σ^2 (sec^2)
240	55.265	5163.72	180,674.85	260	55.265	2201.80	33,358.90
	63.929	3902.89	188,822.06		63.929	2025.34	30,970.23
	72.593	3515.02	222,989.97		72.593	1586.29	36,182.84
	81.257	3399.25	178,840.42		81.257	1441.24	33,945.74
	89.921	3229.86	170,958.34		89.921	1290.99	28,319.48
250	63.929	2821.40	60,254.15	270	55.265	1366.34	20,570.18
	72.593	2431.83	60,081.25		63.929	1325.85	20,794.55
	81.257	2116.04	50,653.64		72.593	1099.45	17,397.54
	89.921	1811.80	41,456.07		81.257	1046.65	16,938.73
					89.921	948.37	16,048.73

Table C.22 The retention times and variances of o-xylene vapour on WH501

T (°C)	Q (cm^3/min)	t_R (sec)	σ^2 (sec^2)	T (°C)	Q (cm^3/min)	t_R (sec)	σ^2 (sec^2)
240	63.929	3311.03	224,685.58	260	55.265	1441.27	27,980.49
	72.593	2748.75	163,840.60		63.929	1219.24	20,336.97
	81.257	2576.38	131,220.39		72.593	1125.50	16,814.97
	89.921	2569.38	124.841,47		81.257	994.39	15,614.31
					89.921	952.80	21,093.27
250	55.265	2275.79	78,845.13	270	55.265	906.63	12,053.80
	63.929	1917.98	66,855.36		63.929	847.20	9,233.34
	72.593	1736.30	41,960.69		72.593	733.90	7,754.86
	81.257	1594.16	32,651.67		81.257	701.11	7,530.37
	89.921	1515.93	30,948.67		89.921	590.31	6,711.12

Table C.23 The retention times and variances of o-xylene vapour on WH502

T (°C)	Q (cm^3/min)	t_R (sec)	σ^2 (sec^2)	T (°C)	Q (cm^3/min)	t_R (sec)	σ^2 (sec^2)
240	63.929	3803.27	167,391.55	260	63.929	1401.59	33,443.08
	72.593	3357.44	227,883.24		72.593	1269.66	22,633.72
	81.257	3069.47	160,860.62		81.257	1182.82	12,599.18
	89.921	2855.77	104,749.06		89.921	1102.27	20,049.46
250	55.265	2395.27	17,851.53	270	63.929	1021.54	7,270.95
	63.929	2381.46	50,761.78		72.593	871.20	10,435.27
	72.593	2002.35	46,455.23		81.257	792.06	7,488.28
	81.257	1911.19	62,159.00		89.921	741.11	11.286.20
	89.921	1695.29	52,995.39				

Table C.24 The retention times and variances of o-xylene vapour on WH503

T (°C)	Q (cm^3/min)	t_R (sec)	σ^2 (sec^2)	T (°C)	Q (cm^3/min)	t_R (sec)	σ^2 (sec^2)
240	55.265	2479.88	274,253.18	260	55.265	1202.57	78,161.74
	63.929	2353.04	221,977.65		63.929	898.15	29,636.56
	72.593	2256.98	211,711.58		72.593	830.21	28,459.55
	81.257	2043.90	208,030.64		81.257	793.93	27,258.42
	89.921	1855.43	142,556.89		89.921	733.92	23,007.87
250	55.265	1785.91	83,946.52	270	55.265	857.14	97,872.09
	63.929	1450.42	69,087.63		63.929	604.69	12,092.76
	72.593	1304.94	58,272.63		72.593	567.67	13,808.88
	81.257	1186.22	54,510.99		81.257	500.96	11,022.76
	89.921	1089.49	46,719.80		89.921	446.46	9,070.28

Table C.25 The retention times and variances of o-xylene vapour on WH601

T (°C)	Q (cm^3/min)	t_R (sec)	σ^2 (sec^2)	T (°C)	Q (cm^3/min)	t_R (sec)	σ^2 (sec^2)
230	72.593	1189.78	81,370.89	250	46.601	717.78	5,842.08
	81.257	1111.43	72,449.56		55.265	590.76	6,684.01
	89.921	1055.49	51,343.54		63.929	546.54	7,021.70
					72.593	487.08	7,009.32
240	55.265	933.83	9,182.17	260	55.265	421.24	2,561.31
	63.929	829.49	9,969.64		63.929	375.41	2,716.71
	72.593	697.36	11,500.49		72.593	322.12	2,812.86
	81.257	659.72	12,583.06		81.257	312.04	2,687.28
					89.921	266.24	2,666.37

Table C.26 The retention times and variances of o-xylene vapour on WH602

T (°C)	Q (cm^3/min)	t_R (sec)	σ^2 (sec^2)	T (°C)	Q (cm^3/min)	t_R (sec)	σ^2 (sec^2)
230	63.929	792.50	20,768.42	250	55.265	566.65	6,786.16
	72.593	695.10	18,427.58		63.929	471.71	5,126.56
	81.257	618.90	10,403.68		72.593	447.16	4,828.75
	89.921	566.32	9,764.89		81.257	419.01	4,051.91
240	55.265	860.82	13,829.15	260	55.265	374.84	3,199.41
	63.929	714.74	11,491.95		63.929	316.77	2,190.47
	72.593	655.29	11,255.04		72.593	295.03	2,215.75
	81.257	618.97	10,981.59		81.257	282.59	2,097.56
	89.921	529.70	7,396.57				

Table C.27 The retention times and variances of o-xylene vapour on WH603

T (°C)	Q (cm^3/min)	t_R (sec)	σ^2 (sec^2)	T (°C)	Q (cm^3/min)	t_R (sec)	σ^2 (sec^2)
240	46.601	541.88	20,941.27	260	37.937	332.34	4,506.06
	55.265	442.36	12,017.65		46.601	274.51	5,345.84
	63.929	388.56	11,016.39		55.265	230.07	2,553.07
	72.593	395.20	8,655.85		63.929	200.93	2,385.68
	81.257	366.56	10,420.30		72.593	184.12	2,273.98
250	46.601	479.12	5,941.85	270	29.273	319.96	2,363.69
	55.265	319.81	3,216.30		37.937	209.33	1,740.18
	63.929	295.97	3,026.85		46.601	205.97	1,470.71
	72.593	261.02	2,445.10		55.265	170.71	1,518.07
	81.257	239.21	2,469.47		63.929	143.77	1,183.36
	89.921	217.53	2,003.36				

APPENDIX D

ADSORPTION EQUILIBRIUM CONSTANTS AND HEAT OF ADSORPTION

Table D.1 Adsorption equilibrium constants of BTX vapours on WH401

Adsorbent	Adsorbates	Temperature (°C)	K	ΔH (kJ/kmol)
WH401	benzene	180	728.15	−73.44
		190	603.82	
		200	341.84	
		210	225.24	
		220	187.84	
		230	105.35	
	toluene	180	3288.54	−81.27
		190	2343.93	
		200	1169.22	
		210	898.62	
		220	546.72	
		230	414.03	
	o-xylene	230	2624.46	−104.37
		240	1251.18	
		250	778.33	
		260	649.94	

Table D.2 Adsorption equilibrium constants of BTX vapours on WH402

Adsorbent	Adsorbates	Temperature (°C)	K	ΔH (kJ/kmol)
WH402	benzene	180	742.01	–71.22
		190	460.60	
		200	347.45	
		210	194.34	
		220	140.29	
		230	123.32	
	toluene	180	4000.92	–86.03
		190	3132.87	
		200	1559.04	
		210	1220.69	
		220	609.05	
		230	466.42	
	o-xylene	230	2999.43	–96.58
		240	1865.49	
		250	1307.11	
		260	796.14	

Table D.3 Adsorption equilibrium constants of BTX vapours on WH403

Adsorbent	Adsorbates	Temperature (°C)	K	ΔH (kJ/kmol)
WH403	benzene	180	897.86	–59.64
		190	852.48	
		200	584.78	
		210	420.93	
		220	289.65	
		230	200.33	
	toluene	180	6996.92	–90.30
		190	4029.11	
		200	2726.67	
		210	2034.07	
		220	1147.10	
		230	555.08	
	o-xylene	240	2781.25	–109.88
		250	2320.12	
		260	1449.74	
		270	663.81	

Table D.4 Adsorption equilibrium constants of BTX vapours on WH501

Adsorbent	Adsorbates	Temperature (°C)	*K*	Δ*H* (kJ/kmol)
WH501	benzene	180	396.26	–53.92
		190	267.29	
		200	181.54	
		210	132.16	
		220	113.69	
		230	97.25	
	toluene	180	3468.99	–58.26
		190	1935.21	
		200	1168.27	
		210	1042.97	
		220	908.29	
		230	658.60	
	o-xylene	240	1959.25	–102.45
		250	1281.08	
		260	829.02	
		270	517.99	

Table D.5 Adsorption equilibrium constants of BTX vapours on WH502

Adsorbent	Adsorbates	Temperature (°C)	*K*	Δ*H* (kJ/kmol)
WH502	benzene	180	612.80	–69.00
		190	465.87	
		200	403.39	
		210	190.20	
		220	137.87	
		230	115.13	
	toluene	180	3085.99	–83.61
		190	2071.81	
		200	1163.55	
		210	924.01	
		220	528.50	
		230	379.04	
	o-xylene	240	2153.87	–96.01
		250	1077.70	
		260	673.67	
		270	637.48	

Table D.6 Adsorption equilibrium constants of BTX vapours on WH503

Adsorbent	Adsorbates	Temperature (°C)	*K*	Δ*H* (kJ/kmol)
WH503	benzene	180	946.27	–95.64
		190	917.26	
		200	435.75	
		210	224.76	
		220	127.14	
		230	102.88	
	toluene	180	2765.96	–70.57
		190	974.81	
		200	831.13	
		210	672.31	
		220	501.88	
		230	320.98	
	o-xylene	240	1270.48	–36.91
		250	1170.17	
		260	921.33	
		270	808.24	

Table D.7 Adsorption equilibrium constants of BTX vapours on WH601

Adsorbent	Adsorbates	Temperature (°C)	*K*	Δ*H* (kJ/kmol)
WH601	benzene	180	1885.97	–84.79
		190	691.16	
		200	563.37	
		210	484.04	
		220	195.06	
		230	182.76	
	toluene	200	3885.92	–93.08
		210	1612.32	
		220	1091.12	
		230	677.52	
		240	551.42	
		250	347.33	
	o-xylene	230	507.13	–69.25
		240	498.14	
		250	291.62	
		260	214.36	

Table D.8 Adsorption equilibrium constants of BTX vapours on WH602

Adsorbent	Adsorbates	Temperature (°C)	*K*	Δ*H* (kJ/kmol)
WH602	benzene	180	1893.95	–69.83
		190	1135.38	
		200	680.75	
		210	513.14	
		220	415.81	
		230	279.95	
	toluene	200	4775.10	–75.55
		210	3798.46	
		220	2016.45	
		230	1872.89	
		240	1230.07	
		250	725.48	
	o-xylene	230	558.31	–89.57
		240	488.16	
		250	275.78	
		260	176.17	

Table D.9 Adsorption equilibrium constants of BTX vapours on WH603

Adsorbent	Adsorbates	Temperature (°C)	K	ΔH (kJ/kmol)
WH603	benzene	180	1359.76	–70.48
		190	920.12	
		200	506.40	
		210	345.88	
		220	280.46	
		230	224.06	
	toluene	200	2499.61	–88.47
		210	1353.41	
		220	867.82	
		230	656.81	
		240	370.41	
		250	284.73	
	o-xylene	240	207.64	–56.17
		250	168.26	
		260	135.22	
		270	99.36	

APPENDIX E

CHARACTERISTICS DATA

Table E.1 Characteristics of carbon adsorbents from rice husk

Characteristic / Carbon adsorbents	BET surface area (m^2/g)	Average pore Size (Å)	Iodine number (mg/g)	Yield (%)
RH401	1008.46	23.80	565	51.71
RH402	1115.64	23.11	567	51.03
RH403	1054.98	23.61	557	50.88
RH501	1130.76	29.09	665	49.32
RH502	1227.42	28.42	668	48.98
RH503	1177.49	28.91	653	48.23
RH601	1084.23	30.20	675	46.91
RH602	1125.56	30.60	717	46.54
RH603	1129.18	29.98	710	45.25
RH401 w/o $ZnCl_2$	26.92	21.05	92	57.80

Table E.2 Characteristics of carbon adsorbents from sugar-cane bagasses

Characteristic / Carbon adsorbents	BET surface area (m^2/g)	Average pore Size (Å)	Iodine number (mg/g)	Yield (%)
SCB401	638.21	15.78	696	34.86
SCB402	1079.54	23.75	749	33.75
SCB403	1076.45	25.03	800	33.01
SCB501	1425.87	40.69	882	31.41
SCB502	1560.19	49.69	887	29.35
SCB503	1446.04	38.62	901	29.03
SCB601	1458.22	59.09	954	27.98
SCB602	1450.54	60.53	1020	27.51
SCB603	1382.55	60.00	1031	27.22
SCB401 w/o $ZnCl_2$	2.22	35.01	319	39.49

Table E.3 Physical properties of the chemical reagents used

Physical Properties \ Chemical Reagents	HNO_3	H_3PO_4	H_2SO_4	HCl	NaCl	$ZnCl_2$
Molecular weight	63	98	98	36.5	58.5	136
Melting point, °C	–41.6	42.35	10.35	–111	800.4	283
Boiling point, °C	86	213	340	–85	1413	732
Solubility, grams per 100 part H_2O	∞	2,340 (26°C)	∞	82.3 (0°C) 56.1 (60°C)	35.7 (0°C) 39.8 (100°C)	432 (25°C) 615 (100°C)
Normal phase	liquid	solid	liquid	gas	solid	solid
Dissociate constant (K_d)	very large	$K_1 = 7.5 \times 10^{-3}$ $K_2 = 6.2 \times 10^{-8}$ $K_1 = 1.0 \times 10^{-12}$	K_1 very large $K_2 = 1.3 \times 10^{-2}$	very large	–	–

Table E.4 Bed characteristics of packed column

Adsorbent-Adsorbate	Mass of Adsorbent (g)	*L* (cm)	ε
WH401B	0.1469	2.0	0.3631
WH402B	0.1207	2.0	0.4252
WH403B	0.0654	1.0	0.3118
WH501B	0.0237	1.0	0.3822
WH502B	0.0555	2.0	0.3219
WH503B	0.0464	1.5	0.3334
WH601B	0.0304	1.0	0.2402
WH602B	0.0274	1.0	0.2860
WH603B	0.0213	1.0	0.3477
WH401T	0.0309	0.5	0.2958
WH402T	0.0334	0.5	0.2969
WH403T	0.0376	0.55	0.2854
WH501T	0.0212	0.5	0.3029
WH502T	0.0336	1.0	0.3587
WH503T	0.0199	0.9	0.3233
WH601T	0.0226	0.7	0.2966
WH602T	0.0145	0.35	0.2644
WH603T	0.0088	0.5	0.3109
WH401X	0.9347	10.0	0.5339
WH402X	0.7624	10.0	0.5116
WH403X	0.8097	10.0	0.4980
WH501X	0.3881	8.0	0.4423
WH502X	0.3148	10.0	0.4883
WH503X	0.2015	6.0	0.4022
WH601X	0.3567	10.0	0.4750
WH602X	0.2676	8.0	0.4076
WH603X	0.2120	8.0	0.4195

Table E.5 Physical properties of benzene, toluene, and o-xylene vapours [Breck, 1974; Reid, 1988; and Perry and Green, 1997]

Property	Benzene	Toluene	O-xylene
Formula	C_6H_6	$C_6H_5(CH_3)$	$C_6H_4(CH_3)_2$
Molecular weight	78.11	92.14	106.2
Boiling point (°C)	80.1	110.6	144.4
Heat of condensation (kJ/mol, at normal boiling point)	30.76	33.5	36.8
Vapor pressure (mmHg, at 30°C)	99.75	38.80	9.12
Antoine equation constants	A = 6.90565	A = 6.95464	A = 6.99891
	B = 1211.033	B = 1344.800	B = 1474.679
	C = 220.790	C = 219.482	C = 213.686
Dipole moment (debye)	0	0.36	0.62
Mean free path (cm)	2.596×10^{-5}	5.4903×10^{-6}	4.86×10^{-6}
Lennard-Jones parameters, σ (Å)	5.27	5.98	6.36

CURRICULUM VITAE

Mr. Chirasak Sangpoum was born in August, 1959 in Nonthaburi Province. He graduated high school from Wat Rachaoros School in 1977. He received a Bachalor's Degree of Science in Chemistry from the Faculty of Science in Khon Kaen University in 1981. In 1986, he received a Master's Degree of Science in Chemical Technology from the Faculty of Science in Chulalongkorn University. Subsequently. he completed requirements for a Doctoral Degree in Chemical Engineering at the Department of Chemical Engineering, the Faculty of Engineering, Chulalongkorn University in 1999. He has been working as a Scientist in the Research and Development Office, Electricity Generating Authority of Thailand (EGAT) since 1987.