EQUILIBRIUM, KINETICS AND THERMODYNAMICS OF ACID DYE ADSORPTION ON PALM OIL EMPTY FRUIT BUNCH

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A project report submitted in partial fulfilment of the requirements for the award of the degree of Master of Science (Chemistry)

Faculty of Science
Universiti Teknologi Malaysia

MAY 2011

Specially dedicated to

my dearest family members for the encouragement, support and inspiration throughout my journey of education.....

ACKNOWLEDGEMENT

In the name of Allah, the Most Gracious and the Most Merciful.

All praised is to Allah S.W.T the sustainer of the world and may there be His blessing to all messengers and His last messenger, the prophet Muhammad S.A.W and his family, companies, followers and the entire believer till the end of time.

First of all, I would like to express most gratitude to my Project Supervisor, Associate Professor Dr. Zaiton Abdul Majid, for her continuous quidance, tolerance and encouragement. Her kindness and generosity in sharing knowledge is much appreciated.

I am also indebted to Universiti Malaysia Sabah (UMS) for funding my Master study. I would also like to express my sincere gratitude to all lecturers and staff in the Department of Chemistry, Universiti Teknologi Malaysia, for their enormous help in my study. I would like to extend my sincere appreciation to other faculties related to my study. Not to forget, thanks to all my friends, colleagues and laboratory personnel who extended their time, advises, technical assistance and expertise during my research.

Lastly, special thanks to all my family members for their encouragement, inspiration and support in completing this study.

ABSTRACT

A low-cost, easily obtained and eco-friendly adsorbents has been investigated as an ideal alternative to the current expensive methods such as using activated carbon for removing dyes from wastewater. This study investigated the use of palm oil empty fruit bunch (POEFB) fibre, an agricultural waste, for the removal of Acid Orange 51 (AO51) dye from aqueous solutions. Batch mode experiments were conducted at room temperature (28 ± 2)°C to study the effect of particle size (75 µm, 250 µm and 2 mm), initial dye concentrations (10-200 mg/L) and temperature (30-50 °C) of adsorption characteristics of AO51 dye onto treated and non-treated POEFB fibre. It was found that the adsorption removal of AO51 dye by treated POEFB fibre was ~5%, which was far lower than that of ~60% on the untreated POEFB fibre. The equilibrium adsorption isotherms and kinetics were further investigated for untreated POEFB fibre. The adsorption equilibrium data were analyzed by Langmuir, Freundlich and Temkin isotherm models. The results indicated that the equilibrium sorption fitted well with the Freundlich isotherm, displaying higher regression coefficient, R^2 value. Adsorption kinetic data were modeled using the pseudo-first-order, pseudo-second-order and intraparticle diffusion models. It was shown that pseudo-second-order kinetic model could best describe the adsorption kinetics. Isotherms have also been used to obtain the thermodynamic parameters, namely enthalpy and entropy of adsorption. The result showed negative value for both enthalpy (-13.91 kJ/mol) and entropy (-38.43 J/mol K) changes. Based on the isotherm studies, it can be concluded that the adsorption of AO51 dye onto untreated POEFB is favorable via physical adsorption. Thermodynamically, the final adsorbed state of the dye molecule is lower in energy compared to initial state. These results indicate the potential of using POEFB fibre as a low-cost adsorbent material for adsorption of the AO51 dye from aqueous solutions.

ABSTRAK

Bahan penjerap kos rendah yang mudah di perolehi dan mesra alam telah dikaji sebagai alternatif yang ideal kepada kaedah semasa yang mahal seperti menggunakan karbon teraktif untuk menyingkirkan pencelup daripada air sisa. Kajian ini mengkaji penggunaan serat buah tandan kosong kelapa sawit, yang merupakan sisa pertanian, untuk menyingkirkan pencelup 'Acid Orange 51' (AO51) daripada larutan air. Ujikaji secara kelompok telah dilakukan pada suhu bilik (28 ± 2 °C) untuk mengkaji kesan saiz zarah (75 µm, 250 µm dan 2 mm), kepekatan awal pencelup (10-200 mg/L), dan suhu (30-50 °C) bagi ciri-ciri penjerapan pencelup AO51 ke atas serat buah tandan kosong kelapa sawit yang dirawat dan tidak dirawat. Didapati bahawa penjerapan penyingkiran pencelup AO51 pada serat buah tandan kosong kelapa sawit yang dirawat adalah ~5%, iaitu sangat rendah berbanding dengan ~60% bagi serat buah tandan kosong kelapa sawit yang tidak dirawat. Keseimbangan penjerapan isoterma dan kinetik dikaji dengan lebih lanjut bagi serat buah tandan kosong kelapa sawit yang tidak dirawat. Data keseimbangan penjerapan dianalisis menggunakan model isoterma 'Langmuir', 'Freundlich' dan 'Temkin'. Hasil menunjukkan bahawa keseimbangan penjerapan berpadanan baik dengan model isoterma 'Freundlich', memaparkan nilai pekali regresi, R^2, yang paling tinggi. Data kinetik penjerapan dimodelkan menggunakan model pseudo tertib pertama, pseudo tertib kedua dan resapan intrazarah. Keputusan menunjukkan bahawa model kinetik pseudo tertib kedua adalah terbaik yang boleh menggambarkan kinetik penjerapan. Isoterma juga digunakan untuk memperoleh parameter termodinamik, yang dinamakan penjerapan entalpi dan entropi. Keputusan menunjukkan nilai negatif untuk kedua-dua perubahan entalpi (-13.91 kJ/mol) dan entropi (-38.43 J/mol K). Berdasarkan kepada kajian isoterma, dapat disimpulkan bahawa penjerapan pencelup AO51 ke atas buah tandan kosong kelapa sawit yang tidak dirawat adalah baik melalui penjerapan fizikal. Secara termodinamiknya, keadaan akhir terjerap bagi molekul pencelup adalah lebih rendah dalam aras tenaga

dibandingkan dengan keadaan awal. Keputusan ini menunjukkan potensi menggunakan serat buah tandan kosong kelapa sawit sebagai bahan penjerap kos rendah untuk penjerapan pencelup AO51 daripada larutan air.

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LIST OF ABBREVIATIONS

AO51	-	Acid Orange 51
BDDT	-	Brunauer, Deming, Deming and Teller
BET	-	Brunauer, Emmett and Teller
EFBU-75	-	Untreated palm oil empty fruit bunch with particle size 75 µm
EFBU-250	-	Untreated palm oil empty fruit bunch with particle size 250 µm
EFBU-2000	-	Untreated palm oil empty fruit bunch with particle size 2000 µm
EFBT-75	-	Treated palm oil empty fruit bunch with particle size 75 µm
EFBT-250	-	Treated palm oil empty fruit bunch with particle size 250 µm
EFBT-2000	-	Treated palm oil empty fruit bunch with particle size 2000 µm
FTIR	-	Fourier Transform Infrared Spectroscopy
IUPAC	-	International Union of Pure and Applied Chemistry
KBr	-	Potassium bromide
POEFB	-	Palm oil empty fruit bunch
SEM	-	Scanning Electron Microscopy
UV-Vis	-	Ultraviolet-Visible Spectroscopy

LIST OF SYMBOLS

a	-	Langmuir constant related to the affinity of the binding site
A	-	Equilibrium binding constant corresponding to the max binding energy
A	-	Absorbance
A_m	-	Average area of one adsorbate molecule in the complete monolayer
b	-	Temkin isotherm constant
b_B	-	Path length/sample cell length
C	-	Concentration
C_0	-	Initial concentration
C_e	-	Equilibrium concentration
C_{Ae}	-	Amount adsorbed on the solid at equilibrium
Hz	-	Hertz
i	-	Intercept of a linear graph
k_1	-	Rate constant of pseudo-first-order adsorption
k_2	-	Rate constant of pseudo-second-order adsorption
k_{diff}	-	Intraparticle diffusion rate constant
k_d	-	Distribution coefficient
K_L	-	Langmuir equilibrium constant
K_F	-	Empirical constant in Freundlich equation
m	-	Weight of adsorbent
M	-	Molar
$\mathrm{N_0}$	-	Avogadro number
P	-	Gas pressure
P	-	Equilibrium pressure
P^0	-	Saturation pressure

q_e	-	Ratio of the weight of adsorbed adsorbate to the weight of adsorbent
q_{max}	-	Maximum adsorption at monolayer coverage
q_t	-	Amount of adsorbate adsorbed at time
R	-	Gas constant (8.314 *J/mol K*)
R_L	-	Separation factor
R^2	-	Correlation coefficient
s	-	Slope of a linear graph
S	-	Specific surface area
S_{BET}	-	BET surface area
T	-	Temperature
V	-	Volume
V_m	-	Volume of gas adsorbed when monolayer coverage is formed
x	-	Mass of adsorbate adsorbed
ε	-	Molar adsortivity
ΔH°	-	Enthalpy change
ΔS°	-	Entropy change
λ	-	Wavelength
λ_{max}	-	Wavelength at which the absorbance is maximum

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CHAPTER I

INTRODUCTION

1.1 Research Background

Environmental pollution problems in Malaysia have a long history. One of the major problems concerning environmental pollutants is wastewater problem. Wastewater comes from domestic and industry. In industry, the biggest sources of industrial wastewater come from textiles, leather, paper, plastic and other dying industries.

The presence of dyes in effluents is a major concern due to their adverse effects to many forms of life. The discharge of dyes in the environment is a matter of concern for both toxicological and esthetical reasons. Industries such as textile, leather, paper and plastics use dyes in order to colour their products and also consume substantial volumes of water. As a result, they generate a considerable amount of coloured wastewater. It is estimated that more than 100,000 commercially available dyes with over 7 x 10^5 tonnes of dyestuff produced annually and from 40,000 to 50,000 tonnes of dye are discharged to surface water every year (Parvathi and Maruthavanan, 2010). It is recognized that the public perception of water quality is greatly influenced by the colour. The colour is the first contaminant to be recognized in wastewater. The presence of even very small amounts of dyes in water (less than 1 mg/L for some dyes) is highly visible and undesirable (Pavan *et. al*., 2007; Rafatullah *et al.*, 2009). Due to large-scale production and extensive application, synthetic dyes can cause considerable environmental pollution and are serious health-risk factors (Forgacsa *et al.*, 2004).

Most dyes are non-biodegradable in nature, which are stable to light and oxidation. Therefore, the degradation of dyes in wastewater either traditional chemical or biological process has not been very effective to treat these effluents. Lots of techniques had been developed in wastewater treatment such as electrolyte extraction, chemical precipitation, evaporation, cementation, adsorption and filtration. Adsorption is the most practised technique among several chemical and physical methods (Alam *et al.*, 2008).

Activated carbon was once a popular choice for removing heavy metals and dyes from wastewater (Babel and Kurniawan, 2003). However, commercially available activated carbon is still considered expensive. This is due to the use of non-renewable and relatively expensive starting material such as coal, which is unjustified in pollution control applications (Martin *et al.*, 2003). This high cost for producing activated carbon had made an essential for researchers to find alternative adsorbents that are lower in cost and as comparable effective as activated carbon.

1.2 Problem Statement

Adsorption on activated carbon is a well-recognized method for the treatment of water and wastewater. The high material cost, however, limits its use in wastewater treatment. Therefore, in recent years, innovative adsorption using locally available low cost adsorbent for dyes removal has been extensively investigated. New economical, easily available and highly effective adsorbents are still needed.

Currently, researchers have worked on palm oil empty fruit bunch as an effective adsorbent for dyes removal. Hameed and El-Khaiary (2008), successfully utilized palm oil empty fruit bunch as a low-cost adsorbent for the removal of hazardous dye like malachite green. The equilibrium adsorption data were analyzed by the Freundlich isotherm, the Langmuir isotherm and the multilayer adsorption isotherm. Ofomaja and Ho, (2007), also revealed the potential of palm oil empty fruit bunch as a good sorbent for the anionic dyes in wastewater.

Several techniques have been used for the treatment of palm oil empty fruit bunch as an effective adsorbent for dyes removal from wastewater such as modifiying the palm oil empty fruit bunch with silylation by trimethylchlorosilane (TMCS) and diethyldichlorosilane (DEDCS) (Rattanawong *et al.*, 2007). Abia and Asuquo (2007), carried out research using mercaptoacetic acid modified palm oil empty fruit bunch adsorbent. Guo and Lua (2003), carried out research by investigating the effects of activation temperature and phosphoric acid impregnation on the textural and chemical properties of the prepared adsorbent.

In other research, the potential use of palm oil empty fruit bunch pretreated with formaldehyde and sulphuric acid for the removal of methylene blue (Saad *et al.*, 2007a) and methyl red (Saad *et al.*, 2007b) dyes from simulated wastewater were also carried out. The data may be useful for designing and fabrication of an economically cheap treatment process.

However, no studies have been reported on the use of palm oil empty fruit bunch for the removal of acid dyes from wastewater. Thus, this study is undertaken to investigate the sorption equilibrium, kinetics and thermodynamics of Acid Orange 51 dye onto palm oil empty fruit bunch.

1.3 Objective of the Study

The objective of this study is to investigate the equilibrium, kinetics and thermodynamics of Acid Orange 51 adsorption onto untreated and acid treated palm oil empty fruit bunch.

1.4 Scope of the Study

In the preparation of treated palm oil empty fruit bunch adsorbent, many factors may affect the percent yield and the quality of product. These factors include the type of chemical activating agent, amount of activating agent, activation temperature and time, as well as washing method. Sulphuric acid (H_2SO_4) was used as the activating agent with the palm oil empty fruit bunch with the ratio 1:1. The activation process was carried out in a muffle furnace for 24 hours at 150 ˚C.

The properties of the prepared adsorbent were characterized by Fourier Transformed Infrared Spectroscopy (FTIR), Scanning Electron Microscopy (SEM) and Nitrogen Adsorption analysis at 77K. The concentration of adsorbate was determined using the Ultraviolet-Visible (UV-Vis) Spectroscopy.

The prepared empty fruit bunch adsorbent was used to adsorb acid dye for the adsorption capacity study. In this study, Acid Orange 51 dye was used as adsorbate. The adsorption capacity of the acid dye onto different particles size of both prepared adsorbents, untreated empty fruit bunch (EFBU) and treated empty fruit bunch (EFBT), were determined and compared. The equilibrium data of the adsorption process was studied using Langmuir, Freundlich and Temkin isotherm while the kinetic of adsorption process was evaluated using Pseudo-first-order, Pseudo-second-order and intraparticle diffusion model. The effects of temperature were also investigated in this study in order to evaluate the adsorption thermodynamic. From this study, the effectiveness of the palm oil empty fruit bunch as adsorbent of removal acid dye was determined.

REFERENCES

Abia, A.A. and Asuquo, E.D. (2007). Kinetics of Cd^{2+} and Cr^{3+} Sorption from Aqueous Solutions using Mercaptoacetic Acid Modified and Unmodified Oil Palm Fruit Fibre (*Elaeis guineensis*) Adsorbent. *Tsinghua Sci. and Tech.* **12**. 485-492.

Alam, M.Z., Muyibi, S.A. and Kamaldin, N. (2008). Production of Activated Carbon from Oil Palm Empty Fruit Bunches for Removal of Zinc. *Proceeding of 12th International Water Technology Conference (IWTC12 2008)* Alexandria, Egypt. 373–383.

Allen, S.J. and Koumanova, B. (2005). Decolourisation of Water/Wastewater Using Adsorption (Review). *J. Uni. Chem. Techn. and Metallurgy*. **40(3)**. 175-192.

Altundogan, H.S., Bahar, N., Mujde, B. and Tumen, F. (2007). The Use of Sulphuric Acid-Carbonization Products of Sugar Beet Pulp in Cr(VI) Removal. *J. of Hazard. And Mat*. **144**. 255-264.

Arivoli, S., Martin, P., Prasath, D. and Thenkuzhali, M. (2007). Adsorption of Chromium Ion by Acid Activated Low Cost Carbon. *Electronic J. Environ. Agricul. Food Chem*. **6**. 2323-2340.

Attia, A.A., Rashwan, W.E. and Khedr, S.A. (2006). Capacity of Activated Carbon in the Removal of Acid Dyes Subsequent to its Thermal Treatment. *Dyes Pigments*. **69**. 128-136.

Babel, S. and Kurniawan, T.A. (2003). Low-Cost Adsorbents for Heavy Metals Uptake from Contaminated Water: A Review. *J. of Hazard. Mat.* **97**. 219–243.

Dabrowski, A. (2001). Adsorption: From Theory to Practice. *Adv. Colloid Interface Sci*. **93**. 135-224.

Foo, K.Y. and Hameed, B.H. (2009). Value Added Utilization of Oil Palm Ash: A Superior Recycling of the Industrial Agricultural Waste. *J. Hazard. Materials*. **172**. 523-531.

Forgacsa, E., Cserhatia, T. and Oros, G. (2004). Removal of Synthetic Dyes from Wastewaters: A review. *Environ. Int.* **30**. 953-971.

Guo, J. and Lua, A.C. (2002). Characterization of Adsorbent Prepared from Oil-Palm Shell by CO_2 Activation for Removal of Gaseous Pollutants. *Mater. Lett*. **55**. 334-339.

Guo, J. and Lua, A.C. (2003). Textural and Chemical Properties of Adsorbent Prepared from Palm Shell by Phosphoric Acid Activation. *Mat. Chem. and Phys*. **80**. 114-119.

Hameed, B.H., Ahmad, A.A. and Aziz, N. (2007). Isotherms, Kinetics and Thermodynamic of Acid Dye Adsorption on Activated Palm Ash. *Chem. Eng. J.* **133**. 195-203.

Hameed, B.H. and El-Khaiary, M.I. (2008). Batch Removal of Malachite Green from Aqueous Solutions by Adsorption on Oil Palm Trunk Fibre: Equilibrium Isotherms and Kinetic Studies. *J. of Hazard. Mat.* **154**. 237-244.

Hasan, M. (2008). *Adsorption of Reactive Azo Dyes on Chitosan/Oil-Palm Ash Composite Adsorbent: Batch and Continuous Studies*. M. Sc. Thesis. University Science of Malaysia.

Ho, Y.S. and Mckay, G. (1999). Pseudo-Second Order Model for Sorption Processes. *Process Biochem*. **34**. 451-465.

Ho, Y.S. and Chiang, C.C. (2001). Sorption Studies of Acid Dye by Mixed Sorbents. *Adsorption*. **7**. 139-147.

Husain, Z., Zainal, Z.A. and Abdullah, M.Z. (2003). Analysis of Biomass-Residue-Based Cogeneration System in Palm Oil Mills. *Biomass Bioenergy*. **24**. 117-124.

Hussain, A., Mohd. Saiyudi, N.K.W. and Abdul Majid, Z. (2008). *Introduction to Surface and Colloid Chemistry*. Monograph 3rd Ed. University Technology of Malaysia.

Jeffree, C.E. and Read, N.D. (1991). *Ambient- and Low-Temperature Scanning Electron Microscopy*. In Hall, J.L. and Hawes, C.R. (Ed.). *Electron Microscopy of Plant Cells.* (pp 313-413). London: Academic Press.

Khalil, H.P.S.A., Alwani, M.S., Ridzuan, R., Kamarudin, H. and Khairul, A. (2008). Chemical Composition, Morphological Characteristics, and Cell Wall Structure of Malaysian Oil Palm Fibers. *Polymer-Plastics Tech. and Eng.* **47**. 273–280.

Kumar, U. (2006). Agricultural Products and By-Products as Low Cost Adsorbent for Heavy Metals Removal from Water and Wastewater. *Scientific Res. and Essay*. **1**. 33-37.

Kumar, A., Prasad, B. And Mishra, I.M. (2008). Adsorptive Removal of Acrylonitrile by Commercial Grade Activated Carbon: Kinetics, Equilibrium and Thermodynamics. *J. Hazard. Materials.* **152**. 589-600.

Marsh, H. (1987). Adsorption Methods to Study Microporosity in Coals and Carbons: A critique. *Carbon*. **25**. 49-58.

Martin, M. J., Artola, A., Balaguer, M. D. and Rigola, M. (2003). Activated Carbons Developed from Surplus Sewage Sludge for the Removal of Dyes from Dilute Aqueous Solutions. *Chem. Eng. J.* **94**. 231-239.

Menon, N.R., Zulkifli, A.R., and Nasrin, A.B. (2003). Empty Fruit Bunches Evaluation: Mulch in Plantation vs. Fuel for Electricity. *J. Oil Palm Ind. Eco.* **3(2)**. 15-20.

Mohan, S.V., Sailaja, P., Srimurali, M. and Karthikeyan, J. (1999). Color Removal of Monoazo Acid Dye from Aqueous Solution by Adsorption and Chemical Coagulation. *Environ. Eng. and Policy*. **1**. 149-154.

Mohan, D., Pittman Jr, C.U., and Steele, P.H. (2006). Pyrolysis of Wood/Biomass for Bio-oil: A Critical Review. *J. Fuel.* **20**. 848-889.

Mohd. Nawawi, M.G., Othman, N., Sadikin, A.N. and Che Ismail, N. (2008). Lignocellulosic Fiber Media Filters as a Potential Technology for Primary Industrial Wastewater Treatment. *Technology*. **49(F)**. 149-157.

Moreira, R., Chenlo, F., Torres, M.D. and Vallejo, N. (2008). Thermodynamics Analysis of Experimental Sorption Isotherms of Loquat and Quince Fruits. *J. Food Eng.* **88**. 514-521.

Mulligan, C.N. (2005). Environmental Application for Biosurfactants. *Environ. Pollution*. **133**. 183

Ofomaja, A.E. and Ho, Y.S. (2007). Equilibrium Sorption of Anionic Dye From Aqueous Solution by Palm Kernal Fibre as Sorbent. *Dyes and Pigments*. **74**. 60-66.

Ofomaja, A.E and Ho, Y.S. (2008). Effect of Temperatures and pH on Methyl Violet Biosorption by Mansonia Wood Sawdust. *Bioresource Technology*. **99**. 5411-5417.

Ong, S.T., Lee, W.N., Keng, P.S., Lee, S.L., Hung, Y.T. and Ha, S.T. (2010). Equilibrium Studies and Kinetics Mechanism for the Removal of Basic and Reactive Dyes in Both Single and Binary Systems using EDTA Modified Rice Husk. *Int. J. Phys. Sci*. **5(5)**. 582-595.

Pandey, K.K and Pitman, A.J. (2003). FTIR Studies of the Changes in Wood Chemistry Following Decay by Brown-Rot and White-Rot Fungi. *Int. Biodeter. Biodegr*. **52**. 151-156.

Parvathi, C. and Maruthavanan, T. (2010). Adsorptive Removal of Megenta MB Cold Brand Reactive Dye by Modified Activated Carbons Derived from Agricultural Waste. *Indian J. Sci. Tech.* **3(4)**. 408-410.

Pavan, F.A., Lima, E.C., Dias, S.L.P. and Mazzocato, A.C. (2007). Methylene Blue Biosorption from Aqueous Solutions by Yellow Passion Fruit Waste. *J. Hazard. Materials.* **150**. 703-712.

Rafatullah, M., Sulaiman, O., Hashim, R. and Ahmad, A. (2009). Adsorption of Methylene Blue on Low-Cost Adsorbents: A Review. *J. Hazard. Materials*. Article in Press.

Rattanawong, O., Kaewsichan, L., Grisdanurak, N. and Yuasa, A. (2007). Sorption of Oil Emulsified in Water on Oil Palm Fibers. *Korean J. Chem. Eng.* **24**. 67-71.

Rozada, F., Otero, M., Mora’n, A.A. and Garcia, A.I. (2008). Adsorption of Heavy Metals onto Sewage Sludge-Derived Materials. *Bioresource Technology*. **99**. 6332-6338.

Ruthven, D.M. (1984). *Principles of Adsorption and Adsorption Processes*. Wiley Int.: New Jersey. 1-10.

Saad, S.A., Daud, S., Kasim, F.H. and Saleh, M.N. (2007a). Dyes Removal from Aqueous Solution by using Chemical Treated Empty Fruit Bunch at Various pH. *Proceeding of the International Conference of Sustainable Materials (ICoSM 2007)*, School of Environmental Engineering, Universiti Malaysia Perlis, Perlis, Malaysia. 297-299.

Saad, S.A., Daud, S., Kasim, F.H. and Saleh, M.N. (2007b). Methylene Blue Removal from Simulated Wastewater by Adsorption using Treated Oil Palm Empty Fruit Bunch. *Proceeding of the International Conference of Sustainable Materials (ICoSM 2007)*, School of Environmental Engineering, Universiti Malaysia Perlis, Perlis, Malaysia. 293-296.

Santanu, P., Manohar, C. and Kartic, K.C. (2005). Adsorption of Anionic and Non-Ionic Surfactants on a Cellulosic Surface. *Colloids and Surfaces A*. **252**. 221-229.

Sulaiman, A., Jaafar, J., Sanagi, M.M., Ahmad, U.K., Wan Ibrahim, W.A. and Ismail, R. (2005). *Modul Pengajaran Kimia Analisis II.* Department of Chemistry, Faculty of Science, UTM. 1-33.

Sulak, M.T., Demirbas, E. and Kobya, M. (2007). Removal of Astrazon Yellow 7GL from Aqueous Solutions by Adsorption onto Wheat Bran. *Biores. Techn.* **98**. 2590-2598.

Sumathi, S., Chai, S.P. and Mohamed A.R. (2008). Utilization of Oil Palm as a Source of Renewable Energy in Malaysia. *Renew. and Sustain. Energy Reviews*. **12**. 2404–2421.

Tamai, H., Yoshida, T., Sasaki, M. and Yasuda, H. (1999). Dye Adsorption on Mesoporous Activated Carbon Fiber Obtained from Pitch Containing Yttrium Complex. *Carbon*. **37**. 983-989.

Tan, I.A.W., Hameed, B.H. and Ahmad, A.L. (2007). Equilibrium and Kinetics Studies on Basic Dye Adsorption by Oil Palm Fibre Activated Carbon. *Chem. Eng. J*. **127**. 111-119.

Tan, I.A.W., Ahmad, A.L. and Hameed, B.H. (2008). Enhancement of Basic Dye Adsorption Uptake from Aqueous Solutions using Chemically Modified Oil Palm Shell Activated Carbon. *Colloids and Surfaces A: Physicochem. Eng. Aspects*. **318**. 88-96.

Tan, L.S., Jain, K. and Rozaini, C.A. (2010). Adsorption of Textile Dye from Aqueous Solution on Pretreated Mangrove Bark, An Agricultural Waste: Equilibrium and Kinetic Studies. *J. App. Sci. Env. Sani*. **5**. 266-276.

Tsai, W.T., Chang, C.Y., Ing, C.H. and Chang, C.F. (2004). Adsorption of Acid Dyes from Aqueous Solution on Activated Bleaching Earth. *J. Colloids and Interface Sci*. **275**. 72-78.

Tsai, W.T., Hsien, K.J., Hsu, H.C., Lin, C.M., Lin, K.Y. and Chiu, C.H. (2008). Utilization of Ground Eggshell Waste as an Adsorbent for the Removal of Dyes from Aqueous Solution. *Bioresource Techn*. **99**. 1623-1629.

Wade Jr, L.G. (2006). *Organic Chemistry*. (6th ed.). Upper Saddle River, N.J.: Prentice Hall.

Weber, W.J. and Morriss, J.C. (1963). Kinetics of Adsorption on Carbon From Solution. *J. Sanit. Eng. Div. Am. Soc. Civil Eng*. **89**. 31-60.

Yin, C.Y., Aroua, M.K. and Daud, W.M.A.W. (2007). Review of Modifications of Activated Carbon for Enhancing Contaminants Uptake from Aqueous Solutions. *Sep. Purif. Techno*. **52**. 403-415.