**Derivation of Oil Palm Shell-based Adsorbent using H2SO4 Treatment for Removal of Atrazine from Aqueous Solutions**

Ivy Tan Ai Wei1\*, Leonard Lim Lik Pueh2, Nor Azalina Rosli2 & Ling Tiew Huang1

*1 Department of Chemical Engineering and Energy Sustainability, Faculty of Engineering, Universiti Malaysia Sarawak, 94300 Kota Samarahan, Sarawak, Malaysia*

*2 Department of Civil Engineering, Faculty of Engineering, Universiti Malaysia Sarawak, 94300 Kota Samarahan, Sarawak, Malaysia*

\*Corresponding Author: *awitan@feng.unimas.my*

**Abstract:** Activated carbon is a prominent material for adsorption of atrazine, however its usage is restricted due to the high cost. Thus, alternative adsorbent derived from agricultural waste has been investigated. This study was conducted to investigate the feasibility of oil palm shell-based adsorbent to remove atrazine from aqueous solutions. Oil palm shell-based adsorbent was prepared using H2SO4 treatment. The adsorbent was characterized for the surface morphology and surface chemistry via scanning electron microscopy (SEM) and Fourier transform infrared (FTIR) spectroscopy. SEM micrographs confirmed that the H2SO4 treatment developed porosity on the surface of the adsorbent. The FTIR spectrum obtained for the adsorbent before and after the treatment was almost similar. Batch adsorption experiments were conducted to determine the effects of initial atrazine concentration (5 - 30 mg/L), contact time, adsorbent dosage (0.2 – 2.0 g) and solution pH (pH 2 - 12) on the adsorption uptake of the adsorbent for atrazine. The adsorption uptake of atrazine increased with increasing initial concentration. The percentage of removal of atrazine increased with increasing adsorbent dosage, but it decreased as the solution pH increased. The equilibrium data were well described by the Freundlich isotherm model. Kinetic studies showed that the adsorption of atrazine on the adsorbent followed the pseudo-second-order kinetic model. Based on the experimental results, it was evident that the oil palm shell-based adsorbent derived in this work might be employed as a low cost adsorbent for removal of atrazine from aqueous solutions.

**Keywords:** *Adsorption, atrazine, isotherm, kinetic, oil palm shell*

**1.0 Introduction**

Atrazine (2-chloro-4-(ethylamino)-6-(isopropylamino)-s-triazine) is a chlorinated s-triazine group of herbicide and is extensively used over the world (Ligy and Pranab, 2006). Atrazine is used extensively as a pre- and post-emergent treatment to control broadleaf and grassy weeds on both agricultural and non-agricultural land (Jamil *et al*., 2011; Mudhoo and Garg, 2011). However, agricultural use of pesticides negatively impacts water quality and poses environmental pollution, even though its use is in a limited amount of compound (Aydinalp and Porca, 2004). Adsorption technique is favourable for atrazine removal due to its simplicity as well as the availability of a wide range of adsorbents. Commercial activated carbon has high adsorption capacity for removal of atrazine. However, the major drawback is its high cost of production, making its usage in removal of atrazine less attractive. Thus, there is a demand for alternative adsorbents, which are of inexpensive materials such as agricultural wastes. Since oil palm shell is abundant in Malaysia, therefore this study aims to investigate the feasibility of oil palm shell-based low cost adsorbent for removal of atrazine from aqueous solutions.

**2.0 Materials and Methods**

*2.1 Materials*

Analytical grade standard of atrazine was used for preparation of stock solution. Analytical grade standard of methanol was used for UV-Visible spectrophotometry analysis of atrazine concentration. Double distilled water was used for purifying adsorbent material and preparing solution samples. Oil palm shell obtained from FELCRA, Kota Samarahan division was selected as raw material to prepare the adsorbent. Oil palm shell granular activated carbon (6 x 12 mesh size) obtained from Bravo Green Sdn. Bhd. was used for comparison with the adsorbent developed for the adsorption studies.

*2.2 Preparation of Adsorbent*

The oil palm shell was washed with double distilled water to remove foreign impurities and the sample was then dried in oven at 50 oC for 48 h. The washed and dried material was ground and sieved to particle size of 0.15 - 0.30 mm. The fibres attached to the surface of oil palm shell were then removed. 300 g of the sieved oil palm shell was soaked in 400 mL of n-hexane to remove oil from the surface of the oil palm shell. The sample was then washed thoroughly with double distilled water and dried in oven at 110 oC for 12 h. The sample was then soaked in 400 mL of 0.1 M sulphuric acid (H2SO4) for 4 h at 30 oC. After the H2SO4 treatment, the adsorbent was washed with hot double distilled water until pH 7 to remove residue H2SO4 and was then dried in oven at 110 oC for 12 h. The dried adsorbents were cooled to room temperature and were stored in air-tight container for further characterization and adsorption studies.

*2.3 Charaterisation of Adsorbent*

The surface morphology of the oil palm shell and oil palm shell-based adsorbent were analyzed by using a scanning electron microscope (Model JEOL JSM-6390LA). The Fourier transform infrared (FTIR) spectroscopy analysis was conducted using FTIR spectrophotometer (Model Shimadzu IRAffinity-1) in the range of 400-4000 cm-1 wavelength with 4 cm−1 resolution. FTIR characterization was used to determine the functional groups present on the surface of the samples.

*2.4 Batch Adsorption Studies*

Stock solution of atrazine of 30 mg/L was prepared by dissolving 30 mg of atrazine in 10 mL of methanol initially in 1000 mL volumetric flask. The solutions were then made up to the volume with double distilled water. Stock solution of atrazine was initially dissolved in a small quantity of methanol in order to accelerate its dissolution in water. The stock solution was then diluted using double distilled water to the desired concentration in the range of 5-30 mg/L. Adsorption studies of atrazine on the oil palm shell-derived adsorbent were carried out in batch mode. Adsorption experiments to study the effect of initial concentration were carried out by contacting 0.2 g of adsorbent with 200 mL of atrazine solution of different concentrations: 5, 10, 15, 20, 25 and 30 mg/L at constant temperature (30 oC) in 250 mL Erlenmeyer flasks. The effect of initial concentration was then evaluated on activated carbon for comparison. The effect of adsorbent dosage on the adsorption of atrazine on oil palm shell-based adsorbent was studied by contacting 200 mL of atrazine solution at fixed concentration of 30 mg/L with various adsorbent dosages of 0.2, 0.4, 0.8, 1.2, 1.6 and 2.0 g at 30 oC in 250 mL Erlenmeyer flasks. Meanwhile, the effect of pH on atrazine adsorption was investigated by contacting 0.2 g of adsorbent with 200 mL of atrazine solution with fixed concentration (5 mg/L) at varying initial solution pH (2-12) at 30 oC.

The absorbance of atrazine at maximum wavelength of 222 nm was plotted against atrazine concentration to obtain a calibration curve for determination of atrazine concentration in this study. The adsorption uptake at time t, qt (mg/g), was expressed by Eq. 1:

qt = (Co- Ct )V/W (1)

where qt is the amount of atrazine adsorbed by adsorbent (mg/g), Co is the initial liquid-phase concentrations of atrazine (mg/L), Ct is the liquid-phase concentration of atrazine at any time t (mg/L) , V is the solution volume (L), and W is the mass of adsorbent used (g).

*2.5 Adsorption Isotherms*

Langmuir and Freundlich isotherm models were employed to fit the equilibrium data to evaluate the equilibrium between adsorbate and adsorbent of the adsorption process. Langmuir isotherm is mainly employed to monolayer adsorption on perfectly smooth and homogeneous surface. The linear form of the Langmuir (Langmuir, 1918) adsorption isotherm equation (Eq. 2) can be expressed as:

Ce/qe = 1/QmKL + (1/Qm) Ce (2)

where Ce is the equilibrium concentration of the adsorbate (mg/L), qe is the amount of adsorbate adsorbed per unit mass of adsorbent (mg/g), Qm and KL are Langmuir constants related to adsorption capacity (mg/g) and rate of adsorption (L/mg), respectively. The plot of Ce/qe against Ce would give the value of Qm and KL.

Freundlich isotherm is extensively applied for adsorption surfaces with non-uniform energy distribution. The linear form of the Freundlich (Freundlich, 1906) adsorption isotherm equation (Eq. 3) can be expressed as:

ln qe = ln KF + (1/n) ln Ce (3)

where KF and n are Freundlich constants which KF is the adsorption capacity of the adsorbent (mg/g)(L/mg)1/n and n is a measure of favourability of the adsorption process. The plot of ln qe against ln Ce would give the value of KF and n.

*2.6 Adsorption Kinetics*

The kinetics data obtained were fitted to pseudo-first-order and pseudo-second-order kinetic models to determine the adsorption mechanism. The pseudo-first-order (Eq. 4) (Kannan and Sundaram, 2001) and pseudo-second-order (Eq. 5) (Yang and Al-Duri, 2005) equations can be expressed as:

ln (qe – qt) = ln qe – k1t (4)

where qe and qt are the amounts of adsorbate adsorbed (mg/g) at equilibrium and at time t, respectively, and k1 is the adsorption rate constant (min-1). Constant k1 and qe could be calculated from the plot of ln (qe – qt) versus time t.

t/qt = 1/k2 qe2 + (1/qe) t (5)

where k2 is the rate constant of second-order adsorption (g/mg min). The plot of t/qt against t would give the value of k2 and qe.

**3.0 Results and Discussion**

*3.1 Characterisation of Adsorbent*

The SEM micrographs of the raw oil palm shell, oil palm shell-based adsorbent treated with H2SO4, activated carbon and oil palm shell-based adsorbent after adsorption of atrazine are presented in Figures 1(a), (b), (c) and (d), respectively. From Figure 1(a), the SEM micrograph shows dirt-covered and unclear pores on the surface of raw oil palm shell. There were very small pores present on the surface of the raw oil palm shell. Chemical activation with H2SO4 on the oil palm shell-based adsorbent resulted in the development of pores, as shown in Figure 1(b). However, the pores developed were not deep enough for high adsorption of atrazine. Meanwhile, the pores found on the surface of the activated carbon were relatively larger. It could be seen that the external surface of activated carbon was full of clear and deep pores, as illustrated in Figure 1(c). Owing to these well-developed pores, the activated carbon possessed higher surface area and adsorptive capacity (Guo and Lua, 1998). From Figure 1(d), it could be observed that there were some atrazine molecules adsorbed on the surface of the oil palm shell-based adsorbent. However, the pores developed on the surface of the adsorbent were slightly being occupied by the atrazine molecules.

|  |  |
| --- | --- |
| (a) | (b) |
| (c) | (d) |

Figure 1: SEM micrographs (3000 x magnification) of (a) Rraw oil palm shell, (b) Oil palm shell-based adsorbent treated with H2SO4, (c) Activated carbon and (d) Oil palm shell-based adsorbent after adsorption of atrazine

From the FTIR spectrum obtained (data not shown), the presence of chemisorbed water and surface hydroxylic groups in raw oil palm shell was indicated by the absorbance peak of O-H stretching vibration between 3450 and 4000 cm-1 (Yacob *et al*., 2008). A weak absorbance peak was observed at 2885.51 cm-1 corresponding to the C–H sp3 stretching (Yacob *et al*., 2008). The C=C stretching vibration of alkynes group was indicated by the absorbance peak between 2200 – 1950 cm-1, indicating the presence of ketones (Guo and Lua, 2002). The strong broad absorbance peak between 1780 – 1640 cm-1 represented the C=O stretching vibration which indicated the presence of quinones (Guo and Lua, 2002). The very strong absorbance peaks at 1525.69 cm-1 and 1024.20 cm-1 were attributed to C=C stretching vibration of aromatic rings and O-H deformation vibration, respectively (Guo and Lua, 2002). The absorbance peak at 1247.94 cm-1 represented the stretching vibration of C–O functional group, indicating the presence of carboxylic acids (Guo and Lua, 1998; Yacob *et al*., 2008). Although the adsorbent was prepared through chemical treatment, it exhibited similarity in the FTIR spectrum with that of raw oil palm shell. This indicated that the chemical treatment with H2SO4 increased the porosity of adsorbent without changing the surface chemistry. However, the absorbance peaks at 1247.94 cm-1 and 1024.20 cm-1 which were assigned to C-O carboxylic acid had been eliminated due to that the sample was washed thoroughly with hot double distilled water to remove any remaining H2SO4. Lower intensity observed at the absorbance peaks between 2200 – 1950 cm-1 could be attributed to the reaction between the sulfuric acid and the oil palm shell. Moreover, the FTIR spectrum of activated carbon also exhibited similar trend as the oil palm shell-based adsorbent.

*3.2 Effect of Contact Time and Initial Atrazine Concentration*

The effect of contact time and initial atrazine concentration on adsorption of atrazine on oil palm shell-based adsorbent and activated carbon are shown in Figures 2 and 3, respectively. Batch adsorption experiments were carried out for 24 h to attain equilibrium. Figure 2 shows that the contact time necessary for adsorption of atrazine on oil palm shell-based adsorbent to reach equilibrium ranged between 150 to 240 min. However, for adsorption of atrazine on activated carbon, longer contact time of 24 h was required to achieve adsorption equilibrium, as shown in Figure 3. It could be seen that the adsorption rate at different concentrations was rapid in the first 15 min and steadily decreased with time until it gradually approached a plateau. The initial rapid uptake could be attributed to the availability of the number of free adsorption sites on the adsorbent and the higher concentration gradient created at the beginning of the adsorption process (Alam *et al*., 2004). As the atrazine loading on the adsorbent increased, the concentration gradient reduced and gave way to a much slower uptake. Furthermore, the atrazine uptake, qt increased with increasing in initial atrazine concentration. The amount of atrazine uptake at equilibrium, qe increased from 0.168 to 3.378 mg/g for oil palm shell-based adsorbent and from 5.392 to 30.734 mg/g for activated carbon, with the increase in the initial atrazine concentrations from 5 to 30 mg/L. The initial concentration provided an important driving force to overcome all mass transfer resistances of the atrazine between the aqueous and solid phases. Hence, a higher initial concentration of atrazine would enhance the adsorption process. Furthermore, the adsorption of atrazine could be described by three consecutive mass transport steps (Alam *et al*., 2007). Firstly, the adsorbate transferred through the solution to the adsorbent exterior surface, followed by adsorbate diffusion into the pores of adsorbent. Finally, the adsorbate was adsorbed into the active sites at the interior of the adsorbent particle. Thus, activated carbon showed a much better adsorption performance than oil palm shell-based adsorbent, which could be attributed to the higher porosity in activated carbon.

*3.3 Effect of Adsorbent Dosage*

Figure 4 shows the removal percentage of atrazine as a function of adsorbent dosage. The removal percentage of atrazine increased from 9.35 to 14.34 % with increasing adsorbent dosage from 0.2 to 2.0 g. This was due to the increase in the number of adsorption sites (Selvaraj *et al*., 1997; Sharma and Forster, 1993). Gupta *et al*. (2011) reported similar trend in the study of pesticides (methoxychlor, atrazine and methyl parathion) removal from waste water on activated carbon prepared from waster rubber tire. It was reported that the increase in adsorbent dosage from 0.2 to 1.6 g resulted in a significant increase in removal percentage of atrazine probably due to a stronger driving force and larger surface area (Gupta *et al*., 2011). Any further increment of the adsorbent did not pose any noticeable change in the removal percentage, which might be due to overlapping of adsorption sites as a result of overcrowding of adsorbent particles (Namasivayam *et al*., 1998).

|  |  |
| --- | --- |
| Figure 2: Time variation of adsorption of atrazine on oil palm shell-based adsorbent at various initial concentrations | Figure 3: Time variation of adsorption of atrazine on activated carbon at various initial concentrations |
| Figure 4: Removal percentage of atrazine on oil palm shell-based adsorbent at different adsorbent dosage | Figure 5: Removal percentage of atrazine on oil palm shell-based adsorbent at different solution pH |

*3.4 Effect of Solution pH*

Figure 5 shows the effect of solution pH on the removal percentage of atrazine on the oil palm shell-based adsorbent. The removal percentage of atrazine decreased from 12.79 to 1.41 % with an increase in the solution pH from 2 to 12. Similar trends had been reported for the adsorption of atrazine (Rafique and Nasreen, 2011), prometryn (Topp *et al*., 1997), imazaqun and imazethapyr (Barriuso *et al*., 1992). As the solution pH increased, the functional groups especially carbonyl and hydroxyl groups became deprotonated, thus leading to development of negative charge at the surface of adsorbent (Gupta *et al*., 2011). At higher pH, a more negatively charged surface of the adsorbent posed stronger electrostatic repulsion for atrazine molecules and thereby decreased the adsorption of atrazine. However, with a decrease in solution pH, the adsorption of atrazine on oil palm shell-based adsorbent increased due to weaker electrostatic repulsion as a result of the reduction in degree of deprotonation (Gupta and Imran, 2008). Besides, atrazine is a weak basic herbicide with pKa value of 1.68. Atrazine could be adsorbed on adsorbent as both protonated and neutral species, depending on the solution pH (Weber, 1970). As the pH values were close to pKa value, atrazine experienced protonization in acidic solutions which favoured hydrogen bond formation or proton transfer, thus resulting in the increase of removal percentage of atrazine (Rafique and Nasreen, 2011). However, atrazine is found as neutral molecule in the environment (pH ≈ 5 to 8) (Colombini *et al*., 1998). Meanwhile, with the increasing of solution pH, weakly basic atrazine became molecular species (Jamil *et al*., 2011). At higher solution pH, a more negative charge developed at the surface of adsorbent and posed a stronger electrostatic repulsion for atrazine molecules, thus resulted in decrease in adsorption of atrazine (Gupta *et al*., 2011).

*3.5 Adsorption Isotherms*

The Langmuir equation is applicable to homogeneous adsorption where the adsorption of each adsorbate molecule on to the surface has equal adsorption activation energy. When Ce/qe was plotted against Ce, a straight line with slope of 1/Qm was obtained. The values of Qm and KL were determined from the Langmuir plots and are presented in Table 1. The adsorption data of atrazine on both oil palm shell-based adsorbent and activated carbon were not fitted well into Langmuir isotherm as the correlation coefficients, R2 obtained were relatively low. Furthermore, the negative values of Langmuir constants for oil palm shell-based adsorbent indicated the inadequacy of Langmuir isotherm to describe the adsorption of atrazine on the adsorbent (Uçar *et al*., 2011). Unlike Langmuir isotherm model, Freundlich model occupies heterogeneous adsorption surface and active sites with different energy (Djebbar *et al*., 2012). The Freundlich equation is suitable for a highly heterogeneous surface and an adsorption isotherm lacking a plateau, indicating a multi-layer adsorption (Daifullah *et al*., 2004). The Freundlich constants KF and intensity n could be calculated from the slope and intercept of the linear plot of ln qe versus ln Ce and the values are presented in Table 1. The correlation coefficient, R2 of Freundlich isotherm for oil palm shell-based adsorbent and activated carbon were 0.995 and 0.888, respectively, indicating that the equilibrium data were better fitted to Freundlich isotherm. Thus, the Freundlich isotherm model was used to estimate the adsorption capacity of the adsorbent for atrazine. The adsorption capacity, KF and intensity n for adsorption of atrazine on oil palm shell-based adsorbent were 0.007 (mg/g)(L/mg)1/n and 0.531, respectively. Furthermore, the value of n was less than one, indicating that the adsorption of atrazine on oil palm shell-based adsorbent was less favorable as compared to activated carbon.

Table 1: Langmuir and Freundlich constants for the adsorption of atrazine on oil palm shell-based adsorbent and activated carbon

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Adsorbents | Langmuir | | | Freundlich | | |
| Qm (mg/g) | KL (L/mg) | R2 | KF (mg/g)(L/mg)1/n | n | R2 |
| Oil palm shell-based adsorbent | -1.065 | -0.034 | 0.713 | 0.007 | 0.531 | 0.995 |
| Activated carbon | 62.058 | 1.196 | 0.626 | 46.462 | 1.321 | 0.888 |

*3.6 Adsorption Kinetics*

The adsorption kinetics data were fitted to the pseudo-first-order and pseudo-second-order kinetic models to evaluate the adsorption mechanism of the adsorption process. Constants k1 and qe for the pseudo-first-order kinetic model could be calculated from the plot of ln (qe – qt) versus time t, and are presented in Table 2. The correlation coefficient, R2 values for the pseudo-first-order kinetic model were lower than those for pseudo-second-order kinetic model at all initial atrazine concentrations. In addition, the pseudo-first-order model gave a relatively large deviation between the calculated and experimental values of qe, indicating that pseudo-first-order model did not appropriately describe the adsorption process of atrazine on oil palm shell-based adsorbent. The pseudo-second-order kinetic model predicted the adsorption behaviour based on the agreement with chemisorption being the rate limiting step (Ho and McKay, 1998). The linear plots of t/qt versus t were plotted. The constants k2 and qe could be calculated from the plots and are shown in Table 2. The pseudo-second-order kinetic model yielded a better fit than the pseudo-first-order kinetic model as the correlation coefficient, R2 values were between 0.951 and 0.999, indicating the applicability of the pseudo-second-order kinetic model to depict the adsorption process of atrazine on oil palm shell-based adsorbent. It could be concluded that the mechanism of adsorption was pseudo-second-order reaction. A better fit to the pseudo-second-order kinetic model suggested that the adsorption rate was dependent more on the availability of the adsorption sites rather than the atrazine concentration (Salman *et al*., 2011).

However, for adsorption of atrazine on activated carbon, the experimental data were better fitted into the pseudo-first-order kinetic model than the pseudo-second-order kinetic model, reflected by the correlation coefficient, R2 values as listed in Table 2. Besides, the qe values predicted by the pseudo-first-order kinetic model agreed well with the experimental qe values, further confirming that the adsorption of atrazine on activated carbon followed the pseudo-first-order kinetic model. Table 2 illustrates that the rate constant k1 decreased with increasing initial atrazine concentrations, which indicated that it was faster for the adsorption of atrazine on activated carbon at lower initial concentrations to achieve equilibrium.

Table 2: Pseudo-first-order and pseudo-second-order constants for adsorption of atrazine on oil palm shell-based adsorbent and activated carbon

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Adsorbents | Initial Conc. (mg/L) | Exp. qe  (mg/g) | Pseudo-first-order model | | | Pseudo-second-order model | | |
| k1 (min-1) | Calc. qe (mg/g) | R2 | k2 (g/mg/min) | Calc. qe (mg/g) | R2 |
| Oil palm shell-based adsorbent | 5 | 0.168 | 0.001 | 0.193 | 0.502 | 0.502 | 0.130 | 0.977 |
| 10 | 0.519 | 0.002 | 0.924 | 0.675 | 0.675 | 0.753 | 0.951 |
| 15 | 1.275 | 0.001 | 2.160 | 0.662 | 0.662 | 1.188 | 0.956 |
| 20 | 2.101 | 0.002 | 2.269 | 0.508 | 0.508 | 2.005 | 0.980 |
| 25 | 2.874 | 0.001 | 2.326 | 0.650 | 0.650 | 2.697 | 0.995 |
| 30 | 3.378 | 0.001 | 3.468 | 0.708 | 0.708 | 3.396 | 0.999 |
| Activated carbon | 5 | 5.209 | 0.005 | 5.618 | 0.992 | 2.037x10-4 | 11.364 | 0.787 |
| 10 | 10.027 | 0.005 | 10.740 | 0.992 | 0.837x10-4 | 24.390 | 0.794 |
| 15 | 14.777 | 0.004 | 14.397 | 0.996 | 3.831x10-4 | 16.667 | 0.917 |
| 20 | 18.385 | 0.004 | 19.240 | 0.995 | 0.563x10-4 | 37.037 | 0.937 |
| 25 | 24.101 | 0.004 | 24.484 | 0.992 | 1.477x10-4 | 27.027 | 0.748 |
| 30 | 29.696 | 0.003 | 28.078 | 0.996 | 2.987x10-4 | 27.027 | 0.892 |

**4.0 Conclusions**

The present study showed that oil palm shell could be used as a potential precursor for the preparation of low cost adsorbent for removal of atrazine from aqueous solutions. SEM micrographs illustrated that chemical treatment with H2SO4 developed porosity on the surface of the adsorbent. The FTIR spectrum obtained for the adsorbent before and after the treatment was almost similar. Over the range of initial concentrations studied, the time for the adsorption of atrazine on the oil palm shell-based adsorbent to attain equilibrium ranged from 150 to 240 min. The adsorption uptake increased with increasing in initial atrazine concentration, with maximum atrazine uptake of 3.86 mg/g at concentration of 30 mg/L. The removal percentage of atrazine increased from 9.35 to 14.34 % with increasing adsorbent dosage from 0.20 to 1.20 g. The removal percentage of atrazine showed a decreasing trend from 12.79 to 1.41 % as the solution pH increased from 2 to 12. The negative values of Langmuir constants indicated that the Langmuir isotherm model was inadequate to describe the adsorption process. The adsorption equilibrium was well described by the Freundlich isotherm model, with correlation coefficient R2 of 0.995, giving adsorption capacity KF of 0.007 (mg/g)(L/mg)1/n at 30 oC. It was found that the adsorption kinetics followed the pseudo-second-order kinetic model. The experimental results revealed that the oil palm shell-based adsorbent developed could be employed as an inexpensive adsorbent for the removal of atrazine from aqueous solutions.

**5.0 Acknowledgements**

The authors acknowledge the research grants provided by Osaka Gas Foundation in Cultural Exchange (OGFICE) Research Grant Scheme and Universiti Malaysia Sarawak under Small Grant Scheme 02(S84)/820/2011(18). The authors would like to thank Bravo Green Sdn. Bhd. for providing the activated carbon.

**References**

Alam, J.B., Dikshit, A.K., and Bandyopadhyay, M. (2004). *Sorption and Desorption of 2,4-D and Atrazine from Water Environment by Waste Tyre Rubber Granules and Its Management*. Global NEST: the International Journal 6: 105-115.

Alam, S., and Bangash, F.K. (2007). *Adsorption of Acid Orange 7 by Activated Carbon Produced from Agriculture Waste: Kinetics*. Journal of the Chemstry Society of Pakistan 29: 558-563.

Aydinalp, C., and Porca, M.M. (2004). *The Effects of Pesticides in Water Resources*. Journal Central European of Agriculture 5: 5-12.

Barriuso, E., Baer, U., and Calvet, R. (1992). *Dissolved Organic Matter and Adsorption–Desorption of Dimefuron, Atrazine and Carbetamide by Soils*. Journal of Environmental Quality 21: 359–367.

Colombini, M.P., Fuoco, R., Giannarelli, S., and Pospísil, L.T. (1998). *Protonation and Degradation Reactions of S-Triazine Herbicides*. Microchemical Journal 59: 239-245.

Daifullah, A.A.M., Girgis, B.S., and Gad, H.M.H. (2004). *A Study of the Factors Affecting the Removal of Humic Acid by Activated Carbon Prepared from Biomass Material*. Colloids and Surface A: Physicochemical Engineering Aspects 235: 1-10.

Djebbar, M., Djafri, F., Bouchekara, M., and Djafri, A. (2012). *Adsorption of Phenol on Natural Clay*. African Journal of Pure and Applied Chemistry 6: 15-25.

Freundlich, H.M.F. (1906). *U ber Die Adsorption in Losungen.* Z. Physical and Chemical 57: 385-470.

Guo, J., and Lua, A.C. (1998). *Characterization of Chars Pyrolyzed from Oil Palm Stones for the Preparation of Activated Carbons*. Journal of Analytical and Applied Pyrolysis 46: 113-125.

Guo, J., and Lua, A.C. (2002). *Characterization of Adsorbent Prepared from Oil Palm Shell by CO2 Activation for Removal of Gaseous Pollutants*. Materials Letters 55: 334-339.

Gupta, V.K., and Imran, A. (2008). *Removal of Endosulfan and Methoxychlor from Water on Carbon Slurry*. Environmental Science and Technology 42: 766-770.

Gupta, V.K., Gupta, B., Rastogi, A., Agarwal, S., and Nayak, A. (2011). *Pesticides Removal from Waste Water by Activated Carbon Prepared from Waste Rubber Tire*. Water Research 45: 4047-4055.

Ho, Y.S., and McKay, G. (1998). *Sorption of Dye from Aqueous Solution by Peat*. Chemical Engineering Journal 70: 115-124.

Jamil, T.S., Gad-Allah, T.A., Ibrahim, H.S., and Saleh, T.S. (2011). *Adsorption and Isothermal Models of Atrazine by Zeolite Prepared from Egyptian Kaolin*. Solid State Science 13: 198-203.

Kannan, N., and Sundaram, M.M. (2001). *Kinetics and Mechanism of Removal of Methylene Blue by Adsorption on Various Carbons - A Comparative Study*. Dyes and Pigments 51: 25-40.

Langmuir, I. (1918). *The Adsorption of Gases on the Plane Surfaces of Glass, Mica and Platinum*. Journal of American Chemistry Society 40: 1361-1403.

Ligy, P., and Pranab, K.G. (2006). *Environmental Significance of Atrazine in Aqueous Systems and Its Removal by Biological Processes: An Overview*. Global NEST Journal 8: 159-178.

Mudhoo, A., and Garg, V.K. (2011). *Sorption, Transport and Transformation of Atrazine in Soils, Minerals and Composts: A Review*. Pedosphere 21: 11-25.

Namasivayam, C., Prabha, D., and Kumutha, M. (1998). *Removal of Direct Red and Acid Brilliant Blue by Adsorption on to Banana Pith*. Bioresource Technology 64: 77–79.

Rafique, U., and Nasreen, S. (2011). *Decontamination of 2, 4-D and Atrazine Through Adsorption on Soil Under Different Modifications and Its Kinetic and Equilibrium Studies*. International Journal of Chemical and Environmental Engineering 2: 227-233.

Salman, J.M., Njoku, V.O., and Hameed, B.H. (2011). *Bentazon and Carbofuran Adsorption onto Date Seed Activated Carbon: Kinetics and Equilibrium*. Chemical Engineering Journal 173: 361-368.

Selvaraj, K., Chandramohan, V., and Pattabhi, S. (1997). *Removal of Cr (VI) from Solution and Chromium Plating Industry Wastewater Using Photofilm Waste Sludge*. Indian Journal of Chemical Technology 18: 641–646.

Sharma, D.C., and Forster, C.F. (1993). *Removal of Hexavalent Chromium Using Sphagnum Moss Peat*. Water Research 27: 1201–1208.

Topp, E., Vallayes, T., and Soulas, G. (1997). *Pesticides: Microbial Degradation and Effects on Microorganisms*. in van Elsas, J.D., Trevors, J.T. and Wellington, E.M.H. (eds.), Modern Soil Microbiology, Mercel Dekker, Inc. New York, USA, 547–575.

Uçar, B., Güvenç, A., and Mehmetoglu, Ü. (2011). *Use of Aluminium Hydroxide Sludge As Adsorbents for the Removal of Reactive Dyes: Equilibrium, Thermodynamic, and Kinetic Studies*. Hydrology Current Research 2: 112.

Weber, J.B. (1970). *Mechanisms of Adsorption of S-Triazine by Clay Colloids and Factors Affecting Plant Availability*. Residue Reviews33: 93-129.

Yacob, A.R., Majid, Z.A., Dasril, R.S.D., and Vicinisvarri, I. (2008). *Comparison of Various Sources of High Surface Area Carbon Prepared by Different Types of Activation*. The Malaysian Journal of Analytical Sciences 12: 264-271.

Yang, X.Y., and Al-Duri, B. (2005). *Kinetic Modelling of Liquid-Phase Adsorption of Reaction Dyes on Activated Carbon*. Journal of Colloid and Interface Science 287: 25-34.