Efficiency of activated carbon from palm kernel shell for treatment of greywater

Mohd Adib Mohammad Razi, Adel Al-Gheethi, Mohammed Al-Qaini and Anwar Yousef

Micropollutant Research Centre, Department of Water and Environmental Engineering, Faculty of Civil & Environmental Engineering, Universiti Tun Hussein Onn Malaysia (UTHM), Johor, Malaysia

ABSTRACT

The potential of activated carbon from palm kernel shell (PKS-AC) to improve the quality of surface water and greywater based on the measurements of the parameters pH, turbidity, chemical oxygen demand (COD), total dissolved oxygen (TDS) and total suspended solids (TSS) was investigated in the present study. The PKS was acid treated with aqueous H3PO4 (1 N) for overnight at room temperature and then subjected to heat treatment at 550 °C for 2 h. The efficiency of the PKS-AC samples of 30 and 40 mm thicknesses was examined for reduction of the above parameters in surface water and greywater samples for 5, 15, 30 and 60 min of the filtration process. The efficiency of COD reduction by 50 and 56.44%, that of TDS by 57.81% and 22%, and that of TSS by 83.11 and 42.11% were detected using the PSK-AC samples above, respectively. The OH group contributed most to the removal of pollutants among the OH, N–H, C=O, C=C, C–O–C, C–O–H main functional groups pointed out via Fourier Transform Infra-red (FTIR) analysis on the surface. The scanning electron microscopy (SEM) images revealed that the surface of the raw PSK-AC appeared smooth with holes on the external surface, while the grains were filled in the PSK-AC after the adsorption process.

1. Introduction

Activated carbon (AC) is the term used to represent a group of absorbing substances of crystalline form with large surface area (1 g of AC has a surface area in excess of 500 m²) and internal pore structures which make the AC more efficient; it is a commonly used absorbent for removal of a wide range of pollutants from wastewater (Askalany et al., 2012). Many materials such as silica gel, zeolites, molecular sieves, activated alumina and synthetic resins are used for the preparation of AC (Zhou et al., 2010). Recently, researchers have moved to using low-cost materials such as cotton silk and coconut shell, saw dust, palm shell, olive stone, walnut shell, grape stalk, bamboo, olive mill, pistachio shell, tropical wood and almond shell (Jankowska et al., 2010). Palm kernel shell (PKS), a by-product of palm oil processing, has a high carbon content, high density and low ash content, and it is produced in large quantities (2 million tonnes annually) in Malaysia. The preparation of AC from natural materials has been reported in the literature (Regti et al., 2017; Selim et al., 2017; Noreen et al., 2017; Bhatti et al., 2017; Shoukat et al., 2017; Tahir et al., 2017). A summary for preparation of AC from coconut and palm shell and its application in the removal of pollutants from wastewater are presented in Table 1. However, the removal efficiency of PKS-AC with regard to pollutants from greywater has not been reported in detail before. Greywater has a different chemical composition than other wastewaters because of the presence of detergents and non-degradable compounds from soap, shampoo and personal care products. This composition might negatively or positively affect the main reduction parameters of greywater, such as chemical oxygen demand (COD), total dissolved solids (TDS), total suspended solids (TSS) and turbidity. Moreover, the direct discharge of greywater into the environment is associated with adverse effects on ecosystems. Some negative effects occur for a short time while others have long-term effects. Nonetheless, the hazard risk for greywater discharge is more associated with the chemical contamination of water bodies which receive released greywater from various sources due to the potential to persist for a long period in the environment (Noman et al., 2019).

In the present study, PKS was used for preparing AC and then the effectiveness of PSK-AC for the...
removal of pollutants from greywater was investigated. The PKS-AC samples were characterized by scanning electron microscopy (SEM) and Fourier Transform Infra-Red (FTIR) analysis techniques.

2. Materials and Methods

2.1. Preparation of PKS-AC

The raw oil palm shells were obtained from a manufacturing company located at Batu Pahat, Malaysia, and dried under sunlight for 3 days. The dried PKS sample was ground first and then sieved to obtain 1–2 mm-sized fractions. Then 30 g of PKS particles were soaked in 100 mL of H2SO4, (1 N) solution for 24 h in order to reduce the amounts of fibre and traces as well as ash content. The PKS particles were washed in distilled water to remove the excess of H2SO4 and dried at 130 °C for 4 h, and then kept at room temperature overnight. The activation process of PKS was carried out by using H3PO4 (1 N) overnight at room temperature. Afterwards, the sample was subjected to heat treatment in a furnace (550 °C) for 2 h, followed by cooling down to room temperature and washing with distilled water three times. Finally, the PKS sample was air dried for 2 h and heated at 130 °C for 4 h.

2.2. Water and wastewater sampling

The water and greywater samples used in this study were obtained at a village area in Tamanu, Batu Pahat, Malaysia. The study area was chosen because the discharge of wastewater into the drainage system is a common practice there. Greywater is discharged directly into the drains as a result of the lack of an effective drainage system. The greywater samples used for the investigation were obtained from the discharge point pipes before the final discharge into main drainage. The quantity of bathroom greywater for each house was estimated by the bucket method (100 L of capacity). The raw surface water samples were taken from drainage and a lake situated at Universiti Tun Hussein Onn Malaysia (UTHM). The pH, turbidity, COD, TDS and TSS of the

| Raw materials          | Preparation method             | Application              | References         |
|------------------------|--------------------------------|--------------------------|--------------------|
| Oil palm stones        | CO2 activation                 | SO2 removal              | Lua and Guo (2001) |
| Coconut shell and palm shell | ZnCl2 and CO2                  | Ammonia adsorption       | Guo and Lua (2003) |
| Palm shell             | H3PO4                          | Iodine                   | Mozammel et al. (2002) |
| Coconut shell          | ZnCl2                          | Nitrogen adsorption      | Daud and Ali (2004) |
| Palm shell and coconut shell | Physical activation (N2 gas) | Cyanide removal          | Jabit (2007)       |
| Palm shell and coconut shell | H3PO4 and ZnCl2               | CO2 adsorption           | Rashidi and Yusuf (2017) |
| Palm shell             | Single (direct) step CO2 activation | Dye removal            | Garcia et al. (2017) |
| Palm shell             | carbonization and ZnCl2        | Wastewater treatment     | García et al. (2017) |
| Palm kernel shells     | Fe3O4/chloride/ferrous sulfate solution |                           |                    |

3. Results and Discussion

3.1. Characteristics of raw water and greywater samples

The characteristics of surface water and greywater samples including the pH, turbidity, COD, TDS and TSS data are presented in Table 2. As can be seen...
from this table, the values of surface water samples are within the Malaysia Drinking Water Standards, whereas the greywater samples have higher values than those recommended by Malaysian Water Standards in terms of pH (8.46) and COD (506 mg/L). The higher pH values of the greywater may be related to the presence of detergents containing organic hydroxyl compounds. These values were higher than those reported by Pogonoski et al. (2016) and Keshavarzifard et al. (2014). In contrast, the concentration of TSS in the present study was much lower than the value (305.0 mg/L) reported by Eze et al. (2015). These differences might be related to the source of greywater; the greywater in the current study was collected from bathroom which has inherent properties such lower amount of TSS in comparison to that generated in kitchen or laundry greywater. COD in the greywater samples tested in the present work was found to be 506 mg/L, which is within the range detected by Mohamed et al. (2013) in Malaysia (445–621 mg/L) but higher than that reported by and Eze et al. (2015). The turbidity value found in the present study was 258 NTU. Therefore the greywater samples should be subjected to further treatment process before final disposal into the surface water systems.

3.2. Efficiency of PKS-AC in reducing parameters of water and greywater

The pH of water and greywater samples during the treatment process using PKS-AC (3 mm and 40 mm of thicknesses) is presented in Figure 1. It can be noted that the pH of the water samples remained constant between 6.2 and 6.8 during the treatment process. In contrast, the pH of the greywater samples decreased from 8.46 to below 6.8 after 30 s of treatment with PSK-AC of 40 mm thickness. The decrease in the pH value of the greywater might be due to the removal of detergent compounds from the waste via adsorption by PSK-AC. Abuagu et al. (2015) indicated that AC has high potential to remove organo-chemical compounds containing detergents and colorants from wastewater.

The reduction in the turbidity of the surface water and greywater is shown in Figure 2. The maximum reduction of the turbidity in the surface water (70%) was recorded with PSK-AC of 40 mm thickness. There was no significant difference in the reduction percentage when the period of the treatment process was increased from 5 to 60 min. The maximum lowering of the turbidity from the greywater was noted after 60 min with the PSK-AC samples of 3 mm and 40 mm thicknesses; however, the removal efficiency with the PSK-AC sample of 40 mm thickness was better than that with the PSK-AC sample of 30 mm thickness (55.3 vs. 44.5%). The turbidity reduction ability of AC from wastewater has been reported previously by Ademiluyi et al. (2009), who claimed that AC from Nigerian-based bamboo removed the turbidity from the refinery effluents completely after 1 h of treatment. In the present study, the maximum removal percentage reached was 55%, which is less than that reported by Ademiluyi et al. (2009). These differences might be ascribed to the different compositions of greywater and refinery effluents.

The maximum removal of COD from surface water and greywater was achieved using the PSK-AC sample of 40 mm thickness (Figure 3). These findings may be related to the thickness of the PSK-AC having more functional groups which contribute effectively in the filtration process, with more efficient adsorption of pollutants than with the 30 mm thickness sample. The COD reduction in surface water reached the highest ratios (50%) after the treatment for 5 and 15 min. Increasing the treatment period to 30 and 60 min reduced the removal of COD, probably due to the interactions occurring between the chemisorbed species on the surface of PSK-AC as well as degradation. The maximum reduction of COD in the greywater was achieved by PSK-AC (thickness: 40 mm) after 30 and 60 min (55.84 vs. 56.44%, respectively). These results revealed the role of PSK-AC in the removal of chemical substances from greywater. It has been demonstrated that the acid-activated coconut shell carbon had higher adsorption for organic matter (Ademiluyi et al., 2009). The higher performance of the AC prepared from bamboo waste (Ahmad and Hameed, 2009) on the reduction of COD from textile mill effluent (75.21%) might be related to the composition of greywater and textile mill effluent. It seems that greywater has less complicated composition than textile mill effluent. However, the chemical composition of the substances in greywater which contribute to the amount of COD is different from that in textile mill effluent. In greywater, most chemical

| Parameter | Surface water samples | Greywater samples | Malaysia drinking water standards |
|-----------|-----------------------|-------------------|-----------------------------------|
| pH        | 6.3                   | 8.46 ± 0.5        | 6.5–9                             |
| Turbidity (NTU) | 27.01 ± 3.7 | 258 ± 6.8        | 5–50                              |
| COD (mg/L) | 26.33 ± 3.78         | 506 ± 50.67       | 25–90                             |
| TDS (mg/L) | 314 ± 49             | 4 ± 1.2           | 0–1000                            |
| TSS (mg/L) | 25.66 ± 3.51          | 26 ± 4.22         | 50                                |

Chemical Oxygen Demand (COD), Total Dissolved Salts (TDS), Total suspended solids (TSS).
substances are soluble in water, while they remain as suspended solids in textile mill effluent (Jamrah et al., 2006).

The TDS removal efficiency of PSK-AC from surface water and greywater is depicted in Figure 4. This figure shows that the reduction of TDS from surface water was more efficient than that from the greywater sample. The highest reduction was achieved after 5 and 15 min (56.25 vs. 57.81%, respectively) with the PSK-AC sample of 4 mm. In the greywater sample, the maximum TDS reduction values recorded after 5 and 15 min with the PSK-AC sample of 4 mm were 22.14 and 21.97%, respectively. The highest reduction of TSS was achieved after 15 and 60 min from surface water (83.11%) and greywater (42.11%), respectively (Figure 5), revealing that PSK-AC acted more efficiently in the reduction of TSS than that of TDS. This behaviour may be explained by the higher affinity shown by TSS than TDS towards the surface of PSK-AC, which facilitates the adsorbate–adsorbent interactions.

The high efficiency of PSK-AC for reduction of COD and TDS may be related to the presence of the function groups acting as adsorbent for the ion cations of the metals as well as the organic compounds, both of which are the main reasons for high COD and TDS in the water. These findings are explained further based on the analysis of functional groups on PSK-AC using FTIR as discussed in section 3.3.

### 3.3. FTIR analysis of PSK-AC

FTIR analysis was performed to identify the main functional groups in the composite adsorbent before and
after the treatment with surface water and greywater, as well as to follow the intensities of the absorption peaks. The spectra were recorded in the wavelength region between 400 and 4000 cm\(^{-1}\). The peaks were obtained through the plot of transmittance against the wave length. There are a number of peaks belonging to different functional groups at characteristic positions with differing intensities (Figure 6). The changes took place in the vibrational stretches of OH, N–H, C=O, C=C, C–O–C, C–O–H out of plane bending in the substituted alcohol and CH=CH. The envelope at 3339 cm\(^{-1}\) revealed the presence of host–guest interactions of a hydrogen-bonded nature (Garg et al., 2008; Koksal et al., 2011). The peak at 1646 cm\(^{-1}\) can be attributed to the C=O and C=O carboxylic groups. The peak at 1647 cm\(^{-1}\) is an indication of stable binding as a result of the chemisorption process. The O–H bonding peak detected in the region between 3000 and 3500 cm\(^{-1}\) for the raw material disappeared in the PSK-AC after the adsorption process, which highlights the role of the OH group in the reduction of pollutants from the wastewater.

3.4. Textural Characterization of PSK-AC

SEM images were obtained to elucidate the surface morphology of the PSK-AC before and after treatment (Figure 7). The samples were coated with platinum.
target before scanning of the images at 1000× magnification. The results showed that the types of processes applied for the preparation of PSK-AC affected the surface morphology. It can be observed that Figure 7a and b show different textural features; Figure 7a has a smooth surface, whereas the surface appears rough in Figure 7b with the observation of dense external surface and closer pores. Some grains were filled, and also cases of evolution of volatiles may be responsible. The PSK-AC was seen to have an uneven, dense texture before and after treatment, which may result from the release of volatile matter during oven drying (Pezoti et al., 2016). The surface of the raw PSK-AC appeared smooth with holes on the external surface, while the grains in PSK-AC were filled during adsorption. The decrease of the pore size was attributed to the occupation of the pore spaces by the solute species in the POME (Peter et al., 2010). Therefore, altering the chemistry, and in particular the pore structure, could lead to significant changes in the surface area, porosity and reactivity of the end product and directly influence the adsorptive properties of AC (Mangun, 2001; Caglar et al., 2013).

4. Conclusion

This paper presents an experimental study on the applicability of AC prepared from PKS as a low-cost adsorbent for treatment of wastewater. PKS-AC exhibited an efficiency of >50% in removing COD from surface and greywater samples. The findings indicated that the removal mechanism of the pollutants by PKS-AC is dependent on the adsorption process proceeding via the surface functional groups available on PSK-AC, as well as the efficacy of sand and gravel which might contribute to the treatment of water. Hence, future work is suggested with further experiments without sand and gravel to establish the efficiency of the PKS-AC. Moreover, the kinetics models for COD, TDS and turbidity removal...
could be performed in a future work. The FTIR analysis of PSK-AC confirmed the OH group as the main functional centre contributing to the reduction of the pollutants from water and greywater. However, in order to make the removal process more efficient by the use of PKS-AC, the optimum treatment parameters, such as the reduction period and costs of removing the pollution from the contaminated water and wastewater, should be tackled in detail.

Acknowledgment
We would like to express our gratitude to the Ministry of Education of Malaysia for the financial support to this work under Fundamental Research Grant Scheme (FRGS: Vot 1456), Department of Environment Malaysia (DOE) and Universiti Tun Hussein Onn Malaysia for the support in preparing this paper. Grateful acknowledgment also goes to all that are involved directly and indirectly in the study.

Disclosure statement
No potential conflict of interest was reported by the authors.

ORCID
Adel Al-Gheethi http://orcid.org/0000-0001-7257-2954

References
Abuq, H. O., Okoye, P. A. C., Ajive, V. I. E., Omuku, P. E., & Umeobika, U. C. (2015). Preparation and characterization of activated carbon produced from oil bean (Ugba or Ukpaka) and snail shell. Journal of Environmental Analytical Chemistry, 2, 165.

Adeleke, A. O., Latiff, A. A. A., Al-Gheethi, A. A., & Daud, Z. (2017). Optimization of operating parameters of novel composite adsorbent for organic pollutants removal from POME using response surface methodology. Chemosphere, 174, 232–242. doi:10.1016/j.chemosphere.2017.01.110

Ademiluyi, F. T., Amadi, S. A., & Amakama, N. J. (2010). Adsorption and treatment of organic contaminants using activated carbon from waste Nigerian bamboo. Journal of Applied Sciences and Environmental Management, 13, 39–47.

Ahmad, A. A., & Hameed, B. H. (2009). Reduction of COD and color of dyeing effluent from a cotton textile mill by adsorption onto bamboo-based activated carbon. Journal of Hazardous Materials, 172, 1538–1543. doi:10.1016/j.jhazmat.2009.08.025

Al-Gheethi, A. A., Efaq, A. N., Mohamed, R. M., Norli, I., & Kadir, M. O. (2017). Potential of bacterial consortium for removal of cephalixin from aqueous solution. Journal of the Association of Arab Universities for Basic and Applied Sciences, 24, 141–148.

Anyika, C., Asri, N. A. M., Majid, Z. A., Yahya, A., & Jaafar, J. (2017). Synthesis and characterization of magnetic activated carbon developed from palm kernel shells. Nanotechnology for Environmental Engineering, 2, 16. doi:10.1007/s41204-017-0027-6

APHA (2005). Standard methods for the examination of water and wastewater, 21st edn. Washington, DC.

Askalany, A. A., Salem, M., Ismail, I. M., Ali, A. H. H., & Morsy, M. G. (2012). A review on adsorption cooling systems with adsorbent carbon. Renewable and Sustainable Energy Reviews, 16, 493–500. doi:10.1016/j.rser.2011.08.013

Bhatti, H. N., Jabeen, A., Iqbal, M., Noreen, S., & Naseem, Z. (2017). Adsorptive behavior of rice bran-based composites for malachite green dye: Isotherm, kinetic and thermodynamic studies. Journal of Molecular Liquids, 237, 322–333. doi:10.1016/j.molliq.2017.04.033

Caglar, B., Afsin, B., Koskal, B., Tabak, A., & Eren, E. (2013). Characterization of unye bentonite after treatment with sulfuric acid. Quimica Nova, 36, 955–959. doi:10.1590/S0100-40422013000700006

Daud, W. M. A. W., & Ali, W. S. W. (2004). Comparison on pore development of activated carbon produced from palm shell and coconut shell. Bioresource Technology, 93, 63–69. doi:10.1016/j.biortech.2003.09.015

Donnet, M., Aimable, A., Lemaître, J., & Bowen, P. (2010). Contribution of aggregation to the growth mechanism of seeded calcium carbonate precipitation in the presence of polyacrylic acid. The Journal of Physical Chemistry B, 114, 12058–12067. doi:10.1021/jp103787p

Eze, V. C., Onwukakor, C. E., & Mgbeokwere, E. U. (2015). Comparative analysis of the microbiological and physico-chemical characteristics of greywater sources in off-campus hostels at michael okpara university of agriculture, umudike, abia state, nigeria. International Journal of Current Microbiology and Applied Sciences, 4, 196–205.

Garcia, J. R., Sedran, U., Zaini, M. A. A., & Zakaria, Z. A. (2017). Preparation, characterization, and dye removal study of carbon prepared from palm kernel shell.

Figure 7. SEM analysis of PSK-AC before (A) and after (B) the adsorption process, Magnification ×1000.
Environmental Science and Pollution Research, 25, 5076–5085.
Garg, U. K., Kaur, M. P., Garg, V. K., & Sud, D. (2008). Removal of nickel (II) from aqueous solution by adsorption on agricultural waste biomass using a response surface methodology approach. Bioresource Technology, 99, 1325–1331. doi:10.1016/j.biortech.2007.02.011
Guo, J., & Lua, A. C. (2003). Textural and chemical properties of adsorbent prepared from palm shell by phosphoric acid activation. Materials Chemistry and Physics, 80, 114–119. doi:10.1016/S0254-0584(02)00383-8
Hu, Z., Srinivasan, M. P., & Ni, Y. (2001). Novel activation process for preparing highly microporous and mesoporous activated carbons. Carbon, 39, 877–886. doi:10.1016/S0008-6223(00)00198-6
Jabit, N. A. (2007). The Production and characterization of activated carbon using local agricultural waste through chemical activation process [TP245. C4 N974 2007 f rb](Ph.D dissertation), Universiti Sains Malaysia.
Jamrah, A., Al-Omari, A., Al-Qasem, L., & Ghani, N. A. (2006). Assessment of availability and characteristics of greywater in Amman. Water International, 31, 210–220. doi:10.1080/025008606.2006.970671
Jankowska, E. A., Rozentryt, P., Witkowska, A., Nowak, J., Hartmann, O., Ponikowska, B., … Ponikowski, P. (2010). Iron deficiency: An ominous sign in patients with systolic chronic heart failure. European Heart Journal, 31, 1872–1880. doi:10.1093/eurheartj/ehq138
Keshavarzifard, M., Zakaria, M. P., Shau Hwai, T., Yusuff, F. I. F., Mustafa, S., Vaezzadeh, V., … Abootalebi-Jahromi, F. (2014). Baseline distributions and sources of polycyclic aromatic hydrocarbons (PAHs) in the surface sediments from the prai and malacca rivers, peninsular malaysia. Marine Pollution Bulletin, 88, 366–372. doi:10.1016/j.marpolbul.2014.08.014
Koksal, B., Afsin, B., Tabak, A., & Caglar, B. (2011). Structural characterization of aniline-bentonite composite by FTIR, DTA/TG, and PXRD analyses and BET measurement. Spectroscopy Letters, 44, 77–82. doi:10.1080/00387010903555953
Lua, A. C., & Guo, J. (2001). Preparation and characterization of activated carbons from oil-palm stones for gas-phase adsorption. Colloids and Surfaces A: Physicochemical and Engineering Aspects, 179, 151–162. doi:10.1016/S0927-7757(00)00651-8
Mangun, C. L., Benak, K. R., Economy, J., & Foster, K. L. (2001). Surface chemistry, pore sizes and adsorption properties of activated carbon fibers and precursors treated with ammonia. Carbon, 39, 1809–1820. doi:10.1016/S0008-6223(00)00319-5
Mohamed, R. M. S. R., Chan, C. M., Ghan, H., Yasin, M. A. M., & Kassim, A. H. M. (2013). Application of peat filter media in treating kitchen wastewater. International Journal of Zero Waste Generation, 1, 11–16.
Mohamed, R. M. S. R., Chan, C. M., Wurochekke, A. A., & Kassim, A. H. B. M. (2017). The use of natural filter media added with peat soil for household greywater treatment. GSTF Journal of Engineering Technology (JET), 2(4).
Montes-Morán, M. A., Suárez, D., Menéndez, J. A., & Fuente, E. (2004). On the nature of basic sites on carbon surfaces: an overview. Carbon, 42, 1219–1225. doi:10.1016/j.carbon.2004.01.023
Mozammel, H. M., Masahiro, O., & Bhattacharya, S. C. (2002). Activated charcoal from coconut shell using ZnCl2 activation. Biomass and Bioenergy, 22, 397–400. doi:10.1016/S0961-9534(02)00015-6
Noman, E. A., Al-Gheethi, A. A. S., Mohamed, R. M. S. R., Talip, B. A., Nagao, H., Kassim, A. H. M., & Bakar, S. A. (2019). Consequences of the improper disposal of grey-water. In Management of Greywater in Developing Countries (pp. 33–50). Cambridge: Springer.
Noreen, S., Bhatti, H. N., Zuber, M., Zahid, M., & Asgher, M. (2017). Removal of actacid orange-rl dye using biocomposites: modeling studies. Polish Journal of Environmental Studies, 26, 21–25.
Peter, M., Ganesh, N., Selvamurugan, N., Nair, S. V., Furuki, T., Tamura, H., & Jayakumar, R. (2010). Preparation and characterization of chitosan-gelatin/nanohydroxyapatite composite scaffolds for tissue engineering application. Carbohydrate, 80, 687–697. doi:10.1016/j.carbpol.2009.11.050
Pezoti, O., Cazetta, A. L., Bedin, K. C., Souza, L. S., Martins, A. C., Silva, T. L., … Almeida, V. C. (2016). NaOH-acti
vated carbon of high surface area produced from guava seeds as a high-efficiency adsorbent for amoxicillin removal: Kinetic, isotherm and thermodynamic studies. Chemical Engineering Journal, 288, 778–788. doi:10.1016/j.cej.2015.12.042
Pogonoski, J. J., Pollard, D. A., & Paxton, J. R. (2016). Conservation overview and action plan for australian threatened and potentially threatened marine and estuarine fishes. Canberra, ACT: Environment Australia 2002.
Rashidi, N. A., & Yusup, S. (2017). Potential of palm kernel shell as activated carbon precursors through single stage activation technique for carbon dioxide adsorption. J Cleaner Production, 168, 474–486. doi:10.1016/j.jclepro.2017.09.045
Regti, A., Laamari, M. R., Stiriba, S. E., & Haddad, M. (2017). Potential use of activated carbon derived from Persea species under alkaline conditions for removing cationic dye from wastewaters. Journal of the Association of Arab Universities for Basic and Applied Sciences, 24, 10–18.
Rugayah, N., & Nuraini, H. (2014). Chicken bone charcoal for defluoridation of groundwater in indonesia. International Journal of Poultry Science, 13, 591–596.
Selim, M. M., El-Mekkawi, D. M., Aboelenin, R. M., Ahmed, S. A. S., & Mohamed, G. M. (2017). Preparation and character-
erization of Na-A zeolite from aluminum scrub and commercial sodium silicate for the removal of Cd2+ from water. Journal of the Association of Arab Universities for Basic and Applied Sciences, 24, 19–25.
Shoukat, S., Bhatti, H. N., Iqbal, M., & Noreen, S. (2017). Mango stone biocomposite preparation and application for crystal violet adsorption: A mechanistic study. Microporous and Mesoporous Materials, 239, 180–189. doi:10.1016/j.micromeso.2016.10.004
Tahir, N., Bhatti, H. N., Iqbal, M., & Noreen, S. (2017). Biopolymers composites with peanut hull waste biomass and application for crystal violet adsorption. International Journal of Biological Macromolecules, 94, 210–220. doi:10.1016/j.ijbiomac.2016.10.013
Zhou, Y., Wu, W., & Qiu, K. (2010). Recovery of materials from waste printed circuit boards by vacuum pyrolysis and vacuum centrifugal separation. Waste Management, 30, 2299–2304. doi:10.1016/j.wasman.2010.06.012