WALAILAK JOURNAL

http://wjst.wu.ac.th

Preparation of Activated Carbon from Bagasse by Microwave-Assisted Phosphoric Acid Activation

Suthatip SINYOUNG¹, Weerawut CHAIWAT² and Kittipong KUNCHARIYAKUN^{3,4,*}

¹Department of Civil Engineering, Faculty of Engineering, Prince of Songkla University, Songkhla 90112, Thailand ²Department of Chemical Engineering, Faculty of Engineering, Mahidol University, Nakhon Pathom 73170, Thailand ³School of Engineering and Technology, Walailak University, Nakhon Si Thammarat 80160, Thailand ⁴Center of Excellence in Sustainable Disaster Management, Walailak University, Nakhon Si Thammarat 80160, Thailand

(*Corresponding author's e-mail: kunchariyakun.k@gmail.com, kittipong.ku@wu.ac.th)

Received: 31 March 2021, Revised: 9 May 2021, Accepted: 16 May 2021

Abstract

This research focuses on the utilization of bagasse as activated carbon (AC) under microwaveassisted phosphoric acid activation. The AC was activated using various frequencies of microwave energy combined with phosphoric acid before the carbonization process. Results indicated that the AC obtained from bagasse under microwave-assisted phosphoric acid had improved properties, i.e. fixed carbon, surface area, and iodine adsorption capacity. However, the loss of AC properties could be attributed to microwave energy exceeding a limit of 800 W. The optimum activated condition in this research was the use of microwave energy 500 W assisted phosphoric acid, which had fixed carbon, surface area, and iodine adsorption capacity at 88.34 ± 0.67 %, 781 m²/g, and 852 ± 6.0 mg/g, respectively.

Keywords: Activated carbon, Bagasse, Microwave energy, Phosphoric acid

Introduction

Activated carbon (AC) is well known as a porous material that can adsorb various matters or pollutants in any state. The applications of AC include medical treatment [1], energy storage [2], water and wastewater treatment [3], and flue gas treatment and adsorption [4]. The use of AC is increasing every year as it is widely used in a variety of applications [5]. The properties of AC can be derived from its high surface area, well-developed internal structure, and presence of various functional groups, which depend on the raw materials and preparation methods. For the preparation methods, activation is the key process to obtain high-quality AC. There are 2 common activation processes: physical activation, e.g. steam and carbon dioxide, and chemical activation, e.g. KOH, NaOH, ZnCl₂, and H₃PO₄. Among both activation processes, chemical activation was noted to be the preferred method because the activation temperature required is relatively low, compared with physical activation [6,7].

Microwave energy is one of the most popular methods used in physical activation, due to this type of energy providing a uniform temperature distribution, a rapid temperature rise, in addition, to being energy-saving [8-10]. The applications of microwave-induced chemical activation have been extensively studied over recent years. [11] noted that the activation via microwave-assisted KOH improved the BET surface area of starch-derived spherical carbon from 8.9 to 616.8 m²g⁻¹. [12] also demonstrated that the AC prepared from cotton stalks by microwave-assisted ZnCl₂ showed the high adsorption ability of

methylene blue. Although the utilization of microwave energy as an activation source can enhance the properties of AC, microwave energy that is too high will lead to the destruction of the pore structure of AC, resulting in inefficiency adsorption [13]. Finding the appropriate microwave energy conditions for each raw material is necessary.

Bagasse is a by-product of the sugar industry, which is around 30 % of the entire plant [14]. The main compounds of bagasse are lignin and cellulose. This leads to bagasse being an effective resource for cheap AC production if prepared under controlled conditions or with appropriate treatments [15]. Hence, in terms of the application of bagasse as AC, this can decrease the volume of agriculture waste and simultaneously produce a valuable adsorbent with cheaper costs than traditional AC [16,17]. In this sense, the focus of this study was to prepare low-cost activated carbon from bagasse by microwave-assisted phosphoric acid activation before the carbonization process. The appropriate activated condition was evaluated on yield, fixed carbon, surface area, functional groups and adsorption capacity.

Materials and methods

Materials

Bagasse was collected from the Prachuap Sugar Industry, Co., Ltd., Kanchanaburi, Thailand. To control for the consistency of bagasse for this study, the whole quantity requirement of bagasse was estimated and collected at one time. The components of bagasse, which consisted of extractive free 3.09 %, cellulose 49.31 %, lignin 23.21 %, and hemicellulose 24.39 % wt. (dry basis), which were carried out using TAPPI (Technical Association of the Pulp and Paper Industry) methods [18-21]. The received bagasse was firstly washed with deionized water to remove any dust and soil and then dried in an electric oven at a temperature of 90 °C overnight. The dried bagasse was ground and sieved to produce particles smaller than 250 μ m (Sieve No. 60). All chemical reagents used in this research were of an analytical grade, such as iodine and phosphoric acid (H₃PO₄).

Determination of optimum carbonized temperature

To determine the optimum carbonized temperature, 2.0 g of ground bagasse was placed in a crucible and then heated using an electric furnace at a rate of 10 °C/min, under N_2 atmosphere, as shown in **Figure 1**. When the temperatures reached the desired temperatures, ranging from 400 - 800 °C, the heat was maintained for 1 h. The fixed carbon contents and the nature of the chemical bonds of the carbonized samples were examined using Thermogravimetric analysis (TGA, TGA8000, Perkin-Elmer, USA) and Fourier transform infrared spectroscopy (FTIR, Model Bruker/Tensor27 method.), respectively. The yields of the carbonized samples based on the dry samples were calculated as shown in Eq. (1). The heating temperature that provided the optimum fixed carbon and yield was selected to prepare the activated carbon in section 2.3.

$$Yield (wt.\%, dry basis) = \frac{w_f}{w_i} \times 100$$
⁽¹⁾

 W_f is the weight of carbonized samples (g) and W_i is the weight of raw ground bagasse (g).



Figure 1 Experiment set up for carbonization process.

Microwave-assisted acid pretreatment of bagasse before carbonization

To prepare activated carbon (AC) from bagasse, 2.0 g of the ground bagasse was immersed in 40 % phosphoric acid with a solid: Liquid ratio of 1 for 24 h. The immersed samples were then subjected to activation via microwave power of 0, 200, 500, and 800 watts for 60 s. After that, the activated samples were rinsed with DI water to remove any excess solution and dried in an electric oven at 110 °C for 24 h. The activated conditions are summarized in **Table 1**. The samples were heated using an electric furnace with the optimum conditions from section 2.2. The activated carbon samples obtained were examined for yield, fixed carbon, FTIR, scanning electron microscopy (SEM, Model Apreo), Brunauer-Emmett-Teller (BET, Model ASAP2460), and iodine absorption capacity. All experiments, i.e., yield, fixed carbon, and iodine absorption capacity, were performed in triplicate.

For iodine absorption capacity analysis, the experiments were performed following ASTM D4607-14. The activated carbon obtained was ground until it passed through a 100-mesh screen. The ground AC was dried at 120 °C for 3 h and then kept in a desiccator until cool. 1 g of dried ground AC was placed into a 250 mL Erlenmeyer flask, and then 10 mL of 5 % hydrochloric acid (HCl) was added. Each flask was swirled gently until the AC was wet and then boiled for 30 ± 2 s for sulfur removal. The flask was cooled to room temperature. 100 mL of 0.1 N iodine solution was added and shaken for 30 ± 1 s. The solution was then filtrated to separate solid and liquid. 50 mL of filtrated solution was added to the 250 mL Erlenmeyer flask and titrated with 0.1 N sodium thiosulfate solution until the solution was a pale yellow color. After that, 2 mL of the starch indicator was added and continuously titrated with 0.1 N sodium thiosulfate solution was recorded and calculated, as shown in Eqs. (2) - (4).

$$\frac{X}{M} = \left[\frac{DF \times B \times S}{M}\right] \tag{2}$$

$$DF = \frac{(N_1 + S)}{F}$$
(3)
(4)

where X/M is iodine absorbed per gram of carbon (mg/g).
S is the volume of sodium thiosulfate (mL).
M is carbon used (g).
DF is dilution factor.
I is the volume of iodine solution (mL).

Walailak J Sci & Tech 2021; 18(16): 22796

3 of 14

llp.//wjsl.wu.ac.lli

H is the volume of 5 % HCl (mL). F is the volume of filtrate (mL). C is the concentration of residual filtrate (N). N₁ is the concentration of sodium thiosulfate (N).

Table 1 The summarization of activated conditions in this research.

Symbols	Details
С	Carbonization without activated process
PC	Activated by H ₃ PO ₄ and then carbonization
PM200C	Activated by H_3PO_4 with a microwave power of 200 W and then carbonization
PM500C	Activated by H_3PO_4 with a microwave power of 500 W and then carbonization
PM800C	Activated by H_3PO_4 with a microwave power of 800 W and then carbonization

Results and discussion

Characteristics of carbonized bagasse

In this investigation, the appropriate carbonized condition for the bagasse was determined in the range of 400 - 800 °C, through yield, fixed carbon content, and FTIR analysis. Figure 2 exhibits the yields and fixed carbon contents at various temperatures, which pronounced that fixed carbon contents increased with an increasing temperature of up to 600 °C, whereas the yields decreased. In terms of FTIR analysis, a broad peak was found at $\approx 3450 \text{ cm}^{-1}$ indicating -OH stretching vibration mode of hydroxyl functional groups [22], as represented in Figure 3. The peak at 1606 cm⁻¹ was characterized as the C=O stretching vibration of lactonic and carbonyl groups [23,24]. Meanwhile, the peak appearing at approximately 1080 cm⁻¹ represented the C-O vibrations of various oxygen-containing groups [25]. The band in the range of 800 - 500 cm⁻¹ could be attributed to C-H and C=CH₂ stretching vibration in aromatic structures [26]. The increase in carbonized temperatures led to the disappearance of the peak at 1606 cm⁻¹ on the carbonized sample at 800 °C. This finding might be related to the reduction of fixed carbon content at high temperatures (above 600 °C). Previous research studies noted that the adsorption capacity not only depends on the surface area, pores volume, and types of pores but also correlates with the concentration of fixed carbon [12,27]. Relatively high fixed carbon provides a high adsorption capacity. Hence, this indicated that the optimum carbonized temperature of this study was 600 °C, giving the yield and fixed carbon contents as 26.63 and 83.95 % by weight, respectively.



Figure 2 Yield and fixed carbon contents of carbonized samples.



Figure 3 FTIR patterns of carbonized samples.

Characteristics of activated carbon from bagasse *Yield and fixed carbon content*

Regarding the previous investigation, the carbonized temperature of 600 °C for 1 h exhibited the optimum condition, consequently, this was applied to synthesize the activated carbon in this section. The properties of the AC obtained were enhanced by pretreatment with 40 % phosphoric acid and microwave energy in the range of 200 - 800 W, before the carbonized process. **Figure 4** shows the yield and fixed carbon contents of activated carbon from bagasse by microwave-assisted phosphoric acid activation. Results showed that the percentage of yield increased when the bagasse was activated by phosphoric acid, as illustrated in **Figure 4(a)**. This was due to the formation of phosphocarbonaceous species and volatile

phosphorous compounds on the surface of bagasse [7,28]. The influence of microwave energy led to a gradual decrease in the yields again due to the thermal degradation of some volatile matter [7,29]. In terms of fixed carbon, this was found to increase with the activation processes, as shown in **Figure 4(b)**. This means that the formation of phosphocarbonaceous species and volatile phosphorous compounds on the surface of bagasse acted in the protection of the carbon skeleton [29]. The increase in microwave energy can contribute to obtaining more active sites on the samples [12]. However, the fixed carbon loss was attributed to the microwave energy increase to 800 W. This means that some phosphocarbonaceous species and volatile phosphorarbonaceous compounds were eliminated.



Figure 4 Yield and fixed carbon contents of activated carbon. (a) Yield and (b) fixed carbon contents.

Fourier transform infrared spectrum (FTIR)

FTIR spectrum was used to identify the functional groups on the surface of the samples. The samples before and after the carbonized process are shown in **Figures 5** and **6**, respectively. Regarding **Figure 5**, it shows that there is a small change between the raw BG and the activated BG. All samples exhibited 2 obvious peaks at the broad peak at ≈ 3450 and 1080 cm^{-1} , and this could be attributed to -OH stretching vibration mode of hydroxyl functional groups and C-O vibrations of various oxygen-containing groups, respectively. The PM800 sample reveals very low intensity at 1080 cm⁻¹, which may imply a loss of functional groups. This finding is related to yield and fixed carbon loss results, as shown in **Figure 3(a)**.

After the carbonized process, the peak at $\approx 3450 \text{ cm}^{-1}$ disappeared for all samples, as given in **Figure 6**. All samples have 4 similar peaks, i.e. at 1606, 1080 cm⁻¹, and the band range of 800 - 500 cm⁻¹. The peaks at 1606 and 1080 cm⁻¹ were attributed to C=O and C-O vibrations, respectively, while the band range of 800 - 500 cm⁻¹ was C-H and C=CH₂ stretching vibrations. This indicated that the activation process seemed to have no significant impact on the functional groups.



Figure 5 FTIR patterns of samples before carbonization process.





Surface area and isotherms

Figure 7 shows the nitrogen adsorption isotherms of activated carbon from bagasse with/without microwave-assisted acid activation pretreatment before carbonization. Results exhibited that all of the isotherms were type I and II according to the IUPAC classification. The initial part of the isotherms is represented as type I with N_2 uptake at low relative pressure, corresponding to adsorption within their micropores. For intermediate and high relative pressure, the isotherms were type II, which obtained a distribution of pore sizes (pore size larger than micropores). This finding agrees with the average pore size, as given in **Figure 8(c)**. According to IUPAC classification, this finding of the average pore size lower than 20 A° (2 nm) in all samples is classified as micropore (microporous materials having pore diameters up to 20 A° (2 nm)) [30].

Increasing the microwave energy up to 500 W resulted in a gradual increase in the N₂ adsorption, surface area, and pore volume, as illustrated in Figures 7 and 8(a) - 8(b). A similar finding was performed by [29], who noted that the development of pore structure was dependent on microwave energy. Based on conventional heating, the heat source heats the carbon materials from the outer surface to its interior via convection, conduction, and radiation mechanisms, which could be non-uniform heating under the difference in the shapes and sizes of carbon materials. Consequently, some volatile components might remain inside the carbon material particles, and provide relatively low total pore volume and BET surface area [6]. Meanwhile, microwave heating is characterized as uniform and volumetric heating, the mechanism of microwave heating affects depolarization and polarization. The carbon materials receive energy through dipole rotation and ionic conduction, and large amounts of heat can be transferred from the interior to the outer surface. Hence, some volatile components that remain inside are eliminated, resulting in pore structure development and a high BET surface area is obtained. However, if the microwave energy is too high (at 800 W), this leads to a reduction in the N₂ adsorption and surface area, including pore volume [12,31-33]. Thus, it can be concluded that the activation using phosphoric acid with microwave energy at 500 W was adequate to develop the highest surface area and N_2 adsorption, including fixed carbon, among the range of activation conditions used in our study.



Figure 7 Nitrogen adsorption isotherms of activated carbons from bagasse by various activated conditions.

Walailak J Sci & Tech 2021; 18(16): 22796



Figure 8 Results of BET analysis. (a) surface area, (b) total pore volume, and (c) average pore size.

Scanning electron microscopy

The morphology of AC obtained in this study was examined using a scanning electron microscope (SEM), as shown in Figure 9. Figure 9(a) shows sphere pores distributed on the surface of a sample without activation, due to the elimination of volatile matter after the carbonization process [34]. The activated samples (Figures 9(b) - 9(e)) also exhibited a porous structure and size similar to the control sample. This means that pretreatment with microwave energy does not affect the pore shape and size of AC obtained. This investigation is related to the BET results.







Figure 9 Morphology of activated carbon from bagasse. (a) C, (b) PC, (c) PM200C, (d) PM500C and (e) PM800C.

Iodine absorption capacity

Typically, the adsorption capacity depends on the amounts of active sites and the porous structure of AC materials [5,13]. The highly porous structure of AC can provide many sites for adsorption, which corresponds to high adsorption efficiency. In this research, the iodine adsorption capacity test was based on the ASTM D4607-94 approach [35], as illustrated in **Figure 10**. Results found that the iodine adsorption capacity was enhanced with the activated process and microwave energy, except at 800 W. The AC prepared by pretreating phosphoric acid with 500 W microwave energy achieved the highest iodine adsorption efficiency of 852 ± 6.0 mg/g. Microwave energy over 500 W attributed to iodine adsorption capacity loss, approximately 281 ± 6.2 mg/g, due to the destruction of the pore structure [13]. This finding corroborated with the surface area and pore volume results, as represented in **Figures 8(a)** - **8(b)**.



Figure 10 Iodine adsorption capacities of activated carbon.

Comparison of the AC produced from various applications of microwave energy

Table 2 shows the comparison of AC obtained in this study with the relevant literature through the preparation method and surface area. The AC obtained exhibited that the application of microwave-assisted phosphoric acid for pretreatment provided the AC with a high surface area of 781 m²/g. Meanwhile, using microwave energy as an activation source after the carbonized process produced a similar grade of AC with a surface area in the range of 570 - 617 m²/g. This denotes that the pretreatment by microwave-assisted phosphoric acid was a potential method for the preparation of a high-grade AC. However, previous research studies recommend that the AC produced by microwave heating (carbonized process) has more efficiency than conventional heating, as represented in surface areas above 790 m²/g. This can be applied in the future study to the preparation method of AC using microwave-assisted phosphoric acid for pretreatment before carbonization by microwave heating. In addition, the other characteristics, such as recyclability and other pollutant absorption capacities, will be investigated in the future to confirm the properties of AC prepared under such conditions, and whether it can be used in the production of commercial absorbent materials.

Raw material	Preparation method	Surface area (m ² /g)	Reference
Bagasse	H ₃ PO ₄ with microwave energy	781	This study
	pretreatment, Conventional heating		
Starch	H_3PO_4 with hydrothermal pretreatment,	616.8	[11]
	KOH with microwave energy activation		
Waste palm shell	Microwave heating, Microwave steam	570.8	[5]
	activation		
Bamboo	H_3PO_4 pretreatment, Microwave heating	1432	[29]
Cotton stalk	ZnCl ₂ pretreatment, Microwave heating	794.8	[12]
Almond shell	H ₃ PO ₄ pretreatment, Microwave, and	1128	[36]
	Conventional heating		
Almond shell	Microwave heating, ZnCl ₂ activation	839	[37]
Pinecone	Microwave heating, ZnCl ₂ activation	939	[38]

Table Companyon of <i>T</i> Columba in this study with the interature	Table 2	Comparisor	n of AC obtained	in this stud	v with the literature
---	---------	------------	------------------	--------------	-----------------------

Walailak J Sci & Tech 2021; 18(16): 22796

11 of 14

Conclusions

The research indicates the high efficiency of AC obtained from bagasse by microwave-assisted phosphoric acid activation. The microwave energy combined with phosphoric acid for activation exhibited a relatively high potential than only phosphoric acid activation. However, the high microwave energy at 800 W has a negative impact on the properties of the AC obtained. The optimum activation condition in this research was microwave energy at 500 W with phosphoric acid which exhibited a high surface area of 781 m²/g, and fixed carbon of 88.34 ± 0.67 %. Such a high surface area resulted in the highest iodine adsorption of 852 ± 6.0 mg/g. Also, the AC obtained in this study exhibited microporous materials, which will be an excellent absorbent material for volatile pollutants removal. This will open the door for the application of this type of AC obtained for commercial absorbent material in the future. Thus, the overall results demonstrated that the activation under microwave-assisted a phosphoric acid is a remarkable approach for converting bagasse into AC with a high surface area and adsorption capacity.

Acknowledgements

The authors appreciate the financial support provided by Walailak University under contract WU_IRG61_32. Ms. Narinthip Suksompong is gratefully acknowledged for her hard-working assistance with the experiments. Moreover, the authors would like to express our sincere gratitude to the Science Laboratory for Education Division, Mahidol University, Kanchanaburi Campus, for research equipment and facilities.

References

- [1] RV Ramanujan, S Purushotham and MH Chia. Processing and characterization of activated carbon coated magnetic particles for biomedical applications. *Mater. Sci. Eng. C* 2007; **27**, 659-64.
- [2] C Liu, BB Koyyalamudi, L Li, S Emani, C Wang and LL Shaw. Improved capacitive energy storage via surface functionalization of activated carbon as cathodes for lithium ion capacitors. *Carbon* 2016; **109**, 163-72.
- [3] RK Liew, C Chai, PNY Yek, XY Phang, MY Chong, WL Nam, MH Su, WH Lam, NL Ma and SS Lam. Innovative production of highly porous carbon for industrial effluent remediation via microwave vacuum pyrolysis plus sodium-potassium hydroxide mixture activation. *J. Clean. Prod.* 2019; **208**, 1436-45.
- [4] T Feng, M Huo, X Zhao, T Wang, X Xia and C Ma. Reduction of SO₂ to elemental sulfur with H₂ and mixed H₂/CO gas in an activated carbon bed. *Chem. Eng. Res. Des.* 2017; **121**, 191-9.
- [5] PNY Yek, RK Liew, MS Osman, CL Lee, JH Chuah, YK Park and SS Lam. Microwave steam activation, an innovative pyrolysis approach to convert waste palm shell into highly microporous activated carbon. *J. Environ. Manag.* 2019; **236**, 245-53.
- [6] W Ao, J Fu, X Mao, Q Kang, C Ran, Y Liu, H Zhang, Z Gao, J Li, G Liu and J Dai. Microwave assisted preparation of activated carbon from biomass: A review. *Renew. Sustain. Energ. Rev.* 2018; 92, 958-79.
- [7] M Myglovets, OI Poddubnaya, O Sevastyanova, ME Lindström, B Gawdzik, M Sobiesiak, MM Tsyba, VI Sapsay, DO Klymchuk and AM Puziy. Preparation of carbon adsorbents from lignosulfonate by phosphoric acid activation for the adsorption of metal ions. *Carbon* 2014; 80, 771-83.
- [8] S Chandrasekaran, T Basak and R Srinivasan. Microwave heating characteristics of graphite based powder mixtures. *Int. Comm. Heat Mass Tran.* 2013; **48**, 22-7.
- [9] Y Fernández and JA Menéndez. Influence of feed characteristics on the microwave-assisted pyrolysis used to produce syngas from biomass wastes. J. Anal. Appl. Pyrol. 2011; 91, 316-22.
- [10] S Ren, H Lei, L Wang, Q Bu, S Chen, J Wu, J Julson and R Ruan. Biofuel production and kinetics analysis for microwave pyrolysis of Douglas fir sawdust pellet. J. Anal. Appl. Pyrol. 2012; 94, 163-69.

- [11] P Liu, Z Wu, X Ge and X Yang. Hydrothermal synthesis and microwave-assisted activation of starch-derived carbons as an effective adsorbent for naphthalene removal. *RSC Adv.* 2019; 9, 11696-706.
- [12] H Deng, L Yang, G Tao and J Dai. Preparation and characterization of activated carbon from cotton stalk by microwave assisted chemical activation: Application in methylene blue adsorption from aqueous solution. *J. Hazard. Mater.* 2009; **166**, 1514-21.
- [13] S Cheng, L Zhang, H Xia, J Peng, J Shu and C Li. Ultrasound and microwave-assisted preparation of Fe-activated carbon as an effective low-cost adsorbent for dyes wastewater treatment. RSC Adv. 2016; 6, 78936-46.
- [14] J Bian, F Peng, XP Peng, P Peng, F Xu and RC Sun. Structural features and antioxidant activity of xylooligosaccharides enzymatically produced from sugarcane bagasse. *Bioresource Tech.* 2013; 127, 236-41.
- [15] EF Mohamed, MA El-Hashemy, NM Abdel-Latif and WH Shetaya. Production of sugarcane bagasse-based activated carbon for formaldehyde gas removal from potted plants exposure chamber. *J. Air Waste Manag. Assoc.* 2015; **65**, 1413-20.
- [16] RH Hesas, A Arami-Niya, WMAW Daud and JN Sahu. Preparation and characterization of activated carbon from apple waste by microwave-assisted phosphoric acid activation: Application in methylene blue adsorption. *Bioresources* 2013; 8, 2950-66.
- [17] NM Mubarak, JN Sahu, EC Abdullah, NS Jayakumar and P Ganesan. Microwave assisted multiwall carbon nanotubes enhancing Cd(II) adsorption capacity in aqueous media. J. Ind. Eng. Chem. 2015; 24, 24-33.
- [18] LE Wise, M Murphy and AAD Adieco. *Chlorite holocellulose, its fractionation and bearing on summative wood analysis and studies on the hemicelluloses*, Vance, Illinois, 1946.
- [19] TAPPI standard T 203 om-93. Alpha-, beta- and gamma-cellulose in pulp and wood. 1998.
- [20] TAPPI standard T 222 om-98. Acid insoluble lignin in wood and pulp. 1998.
- [21] TAPPI standard T 264 om-97. Preparation of wood for chemical analysis. 1997.
- [22] C Aguilar, R García, G Soto-Garrido and R Arriagada. Catalytic wet air oxidation of aqueous ammonia with activated carbon. *Appl. Catal. B. Environ.* 2003; **46**, 229-37.
- [23] ANA El-Hendawy. Influence of HNO₃ oxidation on the structure and adsorptive properties of corncob-based activated carbon. *Carbon* 2003; 41, 713-22.
- [24] C Moreno-Castilla, MV López-Ramón and F Carrasco-Marín. Changes in surface chemistry of activated carbons by wet oxidation. *Carbon* 2000; **38**, 1995-2001.
- [25] V Boonamnuayvitaya, S Sae-ung and W Tanthapanichakoon. Preparation of activated carbons from coffee residue for the adsorption of formaldehyde. *Separ. Purif. Tech.* 2005; **42**, 159-68.
- [26] SW Hao, CH Hsu, YG Liu and BK Chang. Activated carbon derived from hydrothermal treatment of sucrose and its air filtration application. *RSC Adv.* 2016; **6**, 109950-9.
- [27] H Mao, D Zhou, Z Hashisho, S Wang, H Chen, H Wang and MJ Lashaki. Microporous activated carbon from pinewood and wheat straw by microwave-assisted KOH treatment for the adsorption of toluene and acetone vapors. *RSC Adv.* 2015; 5, 36051-8.
- [28] AM Puziy, OI Poddubnaya, RP Socha, J Gurgul and M Wisniewski. XPS and NMR studies of phosphoric acid activated carbons. *Carbon* 2008; 46, 2113-23.
- [29] QS Liu, T Zheng, P Wang and L Guo. Preparation and characterization of activated carbon from bamboo by microwave-induced phosphoric acid activation. *Ind. Crop. Prod.* 2010; **31**, 233-8.
- [30] KSW Sing. Characterization of porous solids: An introductory survey. *Stud. Surf. Sci. Catal.* 1991; 62, 1-9.
- [31] KY Foo and BH Hameed. Coconut husk derived activated carbon via microwave induced activation: Effects of activation agents, preparation parameters and adsorption performance. *Chem. Eng. J.* 2012; **184**, 57-65.
- [32] W Li, LB Zhang, JH Peng, N Li and XY Zhu. Preparation of high surface area activated carbons from tobacco stems with K₂CO₃ activation using microwave radiation. *Ind. Crop. Prod.* 2008; 27, 341-7.

Walailak J Sci & Tech 2021; 18(16): 22796

- [33] KY Foo and BH Hameed. Mesoporous activated carbon from wood sawdust by K₂CO₃ activation using microwave heating. *Bioresource Tech.* 2012; **111**, 425-32.
- [34] M Asadieraghi and WMA Wan Daud. Characterization of lignocellulosic biomass thermal degradation and physiochemical structure: Effects of demineralization by diverse acid solutions. *Energ. Convers. Manag.* 2014; **82**, 71-82.
- [35] ASTM International. ASTM D4607-14: Standard test method for determination of iodine number of activated carbon, ASTM International, Pennsylvania, 2014.
- [36] MS İzgi, C Saka, O Baytar, G Saraçoğlu and Ö Şahin. Preparation and characterization of activated carbon from microwave and conventional heated almond shells using phosphoric acid activation. *Anal. Lett.* 2019; **52**, 772-89.
- [37] D Chunfeng, Y Hongbing, W Zhansheng, G Xinyu, C Giancarlo, Y Bang-Ce and K Imdad. Microwave-assisted preparation of almond shell-based activated carbon for methylene blue adsorption. *Green Process. Synth.* 2016; **5**, 395-406.
- [38] A Özhan, Ö Şahin, MM Küçük and C Saka. Preparation and characterization of activated carbon from pine cone by microwave-induced ZnCl₂ activation and its effects on the adsorption of methylene blue. *Cellulose* 2014; **21**, 2457-67.