

Preparation and Characterization of Activated Carbon from Poplar Sawdust by Chemical Activation: Comparison of Different Activating Agents and Carbonization Temperature

Funda Ateş and Öznur Özcan

Abstract—Activated carbons were prepared from poplar sawdust by chemical activation using $ZnCl_2$, H_3PO_4 or KOH . The influence of activating agents, carbonization temperatures ranging from 500 °C to 800 °C, and mass ratio of chemical agent to precursor (1:1 and 2:1) on the porosity of activated carbons were studied. The properties of the carbons were characterized by adsorption/desorption of nitrogen to determine the BET areas, scanning electron microscopy (SEM) and Fourier-transform infrared spectroscopy (FT-IR). It was determined that the surface morphology and textural characteristics of activated carbons vary depending on the carbonization temperature or chemical agent. Maximum surface areas were obtained at carbonization temperatures of 500, 700 and 800 °C for H_3PO_4 , KOH and $ZnCl_2$ activation, respectively. The activated carbons prepared using $ZnCl_2$ and H_3PO_4 activation had a higher BET surface area (nearly 1100 m^2/g) than that of the KOH activation (761 m^2/g). This study also presents a comparison of mechanisms of activating agents and carbonization temperature. As a result of the experimental studies, positive results were obtained, and the production of activated carbon with a high surface area was conducted.

Index Terms—Biomass; Carbonization; Chemical Activation; Activated Carbon.

I. INTRODUCTION

The structure of activated carbon is formed of a large crystal. It has an improved internal pore structure and a large high internal surface area. It is highly porous over a broad range of pore sizes. Activated carbon pore size distribution is an important property that influences adsorption. The International Union of Pure and Applied Chemistry (IUPAC) classifies the size of pores for adsorbents as micropores ($r < 25$ nm), mesopores ($25 < r < 50$ nm) and macropores ($r > 50$ nm). Macropores exist at the entrance of activated carbon, and serve as carriers. Mesopores contribute to adsorption, whereas adsorption itself takes place on the micropores. The size of pore must conform to the particle diameter of pollutants. If the molecular size of the adsorbate is close to the pore size of the adsorbent, the force of gravity will increase. The surface area of the activated carbon is important, because pollutants are adsorbed on the surface of the activated carbon.

Three main steps are required for the production of activated carbon: the selection of raw material, carbonization and activation. The selection of a suitable raw material is important for the production of activated carbon. The properties of the final product are important in this selection. In addition, quality, price and purity are among those properties that are considered. Carbonization is one of the most important stages in the production of activated carbon. The volatile matter content of the raw material decreases, the elemental carbon content increases and pores are formed in carbonization. The adsorption capacity is measured as a micropore volume or surface area. These features of the solid product obtained from carbonization processes are extremely low. As a result, there needs to be widening of the porosity of the main solid product. This can be achieved by activation processes. Porous carbon adsorbents with a high surface area can be obtained from fossil sources or biomass by physical and chemical activation methods. In the first stage of physical activation, carbonization of the raw material occurs. In the second stage, the char produced in the first stage is activated with water vapor or CO_2 . This activation process occurs at high temperatures. In the chemical activation method, convenient modifications are made by additions of chemical agents to the precursor and the raw material is decomposed in an inert atmosphere. In chemical activation, the carbonization and activation processes take place in a single step. Three chemicals are commonly used; phosphoric acid, zinc chloride, and potassium hydroxide. Activated carbons with a high surface area and pore structure can be produced in high yield by chemical activation. When compared to physical activation, it occurs at lower temperatures.

Lignocellulosic biomass is one of the most abundant renewable energy sources. Activated carbon can be produced at a relatively low cost using biomass as a raw material. Poplar sawdust (PS) is selected as a precursor for activated carbon preparation by chemical activation. These days, sawdust is regarded as an important source of biomass. These raw materials show similarities with woody biomass. They contain cellulose, hemicellulose and lignin in their structure and are known as lignocellulosic materials. A wide variety of activated carbon with different characteristics can be produced depending on the starting material. These include corn cobs [1], bamboo, wheat straw [2], sewage sludge [3], sugar cane bagasse [4], almond shells [5], grape processing industry waste [6], date stones [7], and coconut shells [8] with the activation method used in their

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production.

The objective of this study is the production of porous carbon with a high surface area by chemical activation of poplar sawdust. $ZnCl_2$, H_3PO_4 and KOH are used as chemical agents to improve pore structure. The effects of the carbonization temperature and the chemical agent with different impregnation ratios are studied.

II. EXPERIMENTAL

A. Preparation of Activated Carbons

The poplar sawdust used in the experimental studies was obtained from a sawmill in Eskisehir. In this study, a 20 g precursor was used for all the experiments.

The precursor was ground and sieved to a particle size range of 425– 1250 μm . Ultimate analyses were performed on the sawdust to determine its elemental composition. A Carlo Erba (EA 1108) elemental analyzer was used to determine the weight fractions of carbon, hydrogen, sulfur and nitrogen, with the weight fraction of oxygen being calculated by difference. The ultimate, proximate and component analyses of PS are shown in Table I.

Three chemicals ($ZnCl_2$, H_3PO_4 or KOH) were used as activating reagents.

TABLE I: PROXIMATE, ULTIMATE AND COMPONENT ANALYSIS OF THE PS SAMPLE

Proximate analysis	(wt%)	Ultimate analysis ^b	(wt%)	Component analysis	(wt%)
Moisture	7.9	Carbon	49.8	Cellulose ^d	47.8
Ash	4.0	Hydrogen	6.3	Hemicellulose ^d	19.4
Volatile matter	75.0	Nitrogen	1.0	Lignin ^d	28.6
Fixed carbon ^a	13.1	Oxygen ^a	42.9	Extractives ^c	4.2

^aEstimated by difference; ^bAsh and moisture free

^cBenzene/alcohol (2/1) (v/v); ^dExtractive free basis

In the activation with H_3PO_4 , the precursor was mixed with 89 wt. % H_3PO_4 solution. In the activation with $ZnCl_2$ and KOH, the activating agent was dissolved in water (50 mL) with the resulting solution being physically mixed with the precursors. The ratio of activating agent to precursor varied from 1:1 to 2:1. To ensure the entry of the activating agent into the interior of the precursor, these mixtures were left for 24 hours at room temperature and dried at 100 °C for 48 hours for the preparation of impregnated samples. The samples were then placed in a fixed-bed reactor. The 316 stainless steel reactor had a volume of 400 cm³ (70 mm ID) and was externally heated by an electrical furnace with the temperature being measured by a thermocouple inside the bed. Carbonization temperatures were specified within a temperature range of 500 to 800 °C. The process was carried out in an inert atmosphere using nitrogen gas, supplied at a rate of 100 ml/min. The reactor was programmed with the ramp rate of 10 °C/min. Once the desired carbonization temperature was attained, the reactor was held at the set temperature for 1 hour. Next, the sample was cooled under a nitrogen flow, and the carbonized sample was washed sequentially several times with deionized hot water to remove any residual chemical. The washed sample was dried at 110°C to prepare the activated carbon.

B. Characterization of the Adsorbents

The solid carbon was characterized by determination of micropore area, micropore volume and BET surface area. The surface area and pore volume of the ACs were determined using a surface area analyzer (Micromeritics ASAP 2020) by N₂ adsorption isotherms at 77K. For gas adsorption measurements, the samples were degassed for 7 hours at 150 °C in a vacuum. The surface area was determined by the application of the Brunauer–Emmett–Teller (BET) method. The t-plot method was applied for determination of the surface area of micropores, external surface area and volume of micropores.

The adsorbents were also evaluated using a Scanning Electronic Microscope (SEM) EVO 50 to observe the network of pores.

Surface Functional groups of PS, PS impregnated with chemical agents and ACs were measured on a Bruker Tensor 27 model Fourier Transform Infrared Spectrometer using the KBr pellet technique. A fixed weight of each sample was mixed with KBr before analysis. Spectra from 4000 to 400 cm⁻¹ were recorded. Functional group identification from FTIR spectra was completed using data compiled from the literature [2], [4], [9]-[12].

III. RESULTS AND DISCUSSION

The surface area of PS is 0.041 m²/g, and this needs to be converted into a porous structure with a large surface area before it can be used in an adsorption study. The effect of carbonization temperature on the impregnated precursor has been studied from 500 to 800 °C with the carbonization temperature being found to be important for the development of porosity.

Table II presents the effect of activation temperature, impregnation ratio and activating agents on micropore area and volume.

A. Activation with $ZnCl_2$

Zinc chloride at high concentrations gives Brønsted acidity to the solution. The surface area increases when the temperature is increased from 500 °C to 800 °C and the maximum surface area of 1093.3 m²/g is observed at 800 °C (Table II). An increase in micropore area was observed with increasing temperature, being more noticeable when the impregnation ratio was low. It seems that zinc chloride plays an important role during thermal degradation at higher temperatures [13].

B. Activation with H_3PO_4

As can be seen in Table II, 500 °C is an acceptable carbonization temperature for the formation of micropores and high surface area. H_3PO_4 works effectively as an activating reagent at around 500°C. A decrease in micropore area and micropore volume was observed with increasing temperature. When the activation temperature is higher than 500 °C, micropore structure can be destroyed by collapsing or combining together, resulting in the reduction of microporosity [14]. As the H_3PO_4 concentration increased, BET surface areas of the activated carbons also increased. A maximum surface area of 1133.3 m²/g was obtained when the impregnation ratio was 2/1. At higher concentrations of

H₃PO₄, the development of microporosity was conspicuous. Micropore formation is dominant with the addition of acid to the sample and high micropores means a high surface area.

It is known that the dehydration produced by both zinc chloride and phosphoric acid is strong. Oxygen and hydrogen are removed in this way.

Phosphoric acid promotes bond cleavage reactions and the formation of crosslinks via processes such as cyclization and condensation and combines with organic species to form phosphate bridges, such as phosphate and polyphosphate esters [15], [16].

TABLE II: TEXTURAL CHARACTERISTICS OF ACTIVATED CARBONS OBTAINED BY DIFFERENT IMPREGNATED RATIO, CARBONIZATION TEMPERATURE AND CHEMICAL AGENTS

ZnCl ₂						
IR	T	BSA	MA	ESA	MV	
1/1	500	619.2	350.7	268.5	0.1947	
1/1	700	730.7	512.2	218.5	0.2350	
1/1	800	1093.3	759.0	334.3	0.4696	
2/1	500	548.2	252.0	296.2	0.1588	
2/1	700	696.4	373.3	323.1	0.2074	
2/1	800	955.5	586.0	369.5	0.3956	
H ₃ PO ₄						
IR	T	BSA	MA	ESA	MV	
1/1	500	678.2	362.2	316.0	0.2008	
1/1	700	490.8	258.7	232.1	0.1464	
1/1	800	422.2	225.3	196.9	0.1290	
2/1	500	1133.3	633.2	500.1	0.4421	
2/1	700	760.7	474.9	285.8	0.2701	
2/1	800	528.4	287.5	240.9	0.1765	
KOH						
IR	T	BSA	MA	ESA	MV	
1/1	500	385.9	254.7	131.2	0.1674	
1/1	700	761.2	628.8	132.4	0.3425	
1/1	800	635.4	546.5	88.9	0.3036	
2/1	500	245.8	193.7	52.1	0.2368	
2/1	700	623.6	480.6	143.1	0.2715	
2/1	800	474.1	289.3	184.8	0.1581	

IR: Impregnation rate; T: Temperature (°C);
BSA: BET surface area (m² g⁻¹); MA: Micropore area (m² g⁻¹);
ESA: External surface area (m² g⁻¹); MV: Micropore volume (cm³ g⁻¹)

C. Activation with KOH

It can clearly be seen from Table II that activated carbon with the highest microporosity is obtained at a temperature of 700 °C. The surface areas increase from temperatures of 500 to 700 °C, and then decrease with a further increase of temperature from 700 to 800 °C. This suggests a critical temperature range of activation by KOH.

A maximum surface area of 761.2 m²/g is obtained when the impregnation ratio is 1/1. The effects of KOH can be explained in the following way: During the carbonization process, KOH melts (around 360 °C), with the melted KOH and precursor then contacting one another before the reaction temperature is reached [17], and the oxygen of the alkali removing cross-linking and stabilizing carbon atoms in crystallites [16]. This mechanism creates more microporosity. As can be seen in Table II, activated carbons obtained with KOH activation have the highest ratio of micropore area/external surface area. As a consequence of the KOH chemical activation, there was an increase in the number of micropores.

D. Comparison of Mechanisms of Activating Agents and Temperature

Chemical agents produce chemical changes and structural alterations. They accelerate the decomposition of a precursor and inhibit the formation of tar. The precursor is impregnated with an activating agent with different impregnation ratios before carbonization. Impregnation causes fragmentation of the biomass components, such as cellulose, hemicellulose and lignin. Effectively, the reaction of the precursor with chemical reagents begins as soon as the components are mixed. Pore opening varies depending on the chemical used and carbonization temperature. In activated carbons, the original morphology of the precursor is lost because most of the structure has been degraded. As a result, the micro, meso and macroporous structure of the product are formed.

In summary, it is found that:

- 1) The maximum value surface area was obtained with at temperatures of 500 °C, 700 °C and 800 °C with H₃PO₄, KOH and ZnCl₂ activation, respectively.
- 2) Maximum surface areas were observed around 1100 m²/g using ZnCl₂ and H₃PO₄ as activating reagent. The ZnCl₂ and H₃PO₄ activation increased the BET surface area of the samples more than that of the activation with KOH.
- 3) Maximum micropore volumes were determined as 0.47 cm³g⁻¹ for ZnCl₂, 0.44 cm³g⁻¹ for H₃PO₄ and 0.34 cm³g⁻¹ for KOH.
- 4) It can be seen that impregnation ratio is an important variable, which can be used to obtain high surface area activated carbon. 1/1 ratio for both ZnCl₂ and KOH gives the highest microporosity. At higher ratios, the microporosity decreases slightly. After a certain point, higher impregnation ratios can result in the widening of micropores and the formation of meso and macropores. Therefore, the surface area of the carbons decreases [18]. Microporosity of the activated carbons is developed with increasing concentrations of H₃PO₄.
- 5) ZnCl₂ and H₃PO₄ create a dehydrating effect on the biomass components during heat treatment. However, this effect does not appear with KOH [13].
- 6) ZnCl₂ and H₃PO₄ develop both micropores and mesopores and KOH develops effectively microporosity with some mesopores.

E. FTIR analysis

FTIR is perhaps the most powerful tool for identifying types of chemical bond (functional groups). The PS, impregnated sample with chemical agents and activated carbons (ACs) were analyzed by FTIR to clarify the structural changes after the activation and carbonization processes. The assignments of the absorption bands are listed in Table III. The precursor contained many more bands than the impregnated raw material and ACs. The precursor shows a wide band at 3550 cm⁻¹ which is assigned to the O-H stretching modes of the hydroxyl groups and adsorbed water. The adsorption bands at 2926 cm⁻¹ are assigned to the asymmetric C-H stretching from the methyl and methylene groups [2], [3]. The most intense bands are observed between 1750 and 1050 cm⁻¹. The band at about

1737 cm^{-1} is assigned to the C=O stretching vibration of the carboxyl, aldehyde, ketone and ester groups. The peaks between 1620 and 1580 cm^{-1} represent aromatic C=C vibration [12]. The peak between 1174 and 1050 cm^{-1} , and

808 and 780 cm^{-1} , are associated with the inplane and out-of-plane aromatic ring deformation vibrations, respectively [3], [19].

TABLE III: PEAK ASSIGNMENTS OF FUNCTIONAL GROUP OF PS, IMPREGNATED PS WITH CHEMICAL AGENTS AND ACTIVATED CARBONS

WN	PS	I-PS- ZnCl ₂	I-PS- H ₃ PO ₄	I-PS- KOH	AC _{ZnCl2} (500 °C)	AC _{ZnCl2} (800 °C)	AC _{H3PO4} (500 °C)	AC _{H3PO4} (800 °C)	AC _{KOH} (500 °C)	AC _{KOH} (800 °C)
3600-3400 O-H stretching	3550	3496	3448	3440	---	---	---	---	---	---
2930-2850 Aliphatic C-H stretching	2926	2929	2930	2928	---	---	---	---	---	---
1740-1700 C=O stretching	1737	---	---	---	---	---	---	---	---	---
1620-1580 Aromatic C=C stretching	1610	1619	1612	1582	1581	---	1580	---	---	---
1260-1250 C-O stretching	1250	1257	1254	1257	---	---	---	---	---	1259
In plane C-H bending (Aromatic)	1052	1057	1018	1094	1094	1090	1146	1064	1174	1090
Out of plane C-H bending (Aromatic)	782	787	808	782	806	802	806	802	800	806

WN: wave number (cm^{-1}); I-PS-ZnCl₂: Impregnation PS with ZnCl₂; I-PS-H₃PO₄: Impregnation PS with H₃PO₄; I-PS-KOH: Impregnation PS with KOH

These bands decrease markedly or disappeared on the spectra of the impregnated samples and activated carbons. A decrease in the intensity of the O-H absorption band is observed, indicating that the hydroxyl groups are reduced by impregnation of raw material. The reaction between precursor and chemical agent probably begins as soon as the components mix. This can be explained by the dehydrating effect of the chemical agents on the precursor.

As a result of the activation and carbonization processes, most of the spectral features are lost. The intensities of peaks related to O-H, C-O, C=O and the aliphatic C-H groups on the surface of the PS reduce or disappear on the surface of the impregnated raw materials. This is obviously related with the activating process. In addition, activated carbons effectively do not have the same species of functional groups as the raw material. The O-H, C-O and C=O groups disappear on the surface of the ACs. These findings are related to the carbonization process, as well as activation. These findings confirm the removal of oxygen functionalities from the surface of activated carbons. The C-H symmetric and asymmetric vibration modes of the ethyl and methylene groups almost disappear for activated carbons. This means that a large portion of the hydrogen element is removed. As a result of the loss of a number of functional groups, such as hydroxyl and aliphatic, a fused-ring structure occurs and pore formation is enhanced [2].

F. Surface Morphology of Activated Carbons

SEM is used to observe the surface morphology of the raw material and ACs (Fig. 1). Surface morphology has a characteristic role in determining areas of adsorption. High surface areas increase the contact efficiency between the contaminant to be removed and the carbon [20].

The raw material exhibits groove form with parallel streaks on the surface (Fig. 1A). It is difficult to see the pores on the surface of the precursor. Surface morphology differs greatly between precursor and ACs. Porosity is created during the carbonization process of an organic precursor and

the removal of volatiles eliminates the hydrogen and oxygen atoms and creates a different structure from the original precursor. Carbon atoms combine with other near-neighbor-carbon atoms and create maximum stability positions [13].

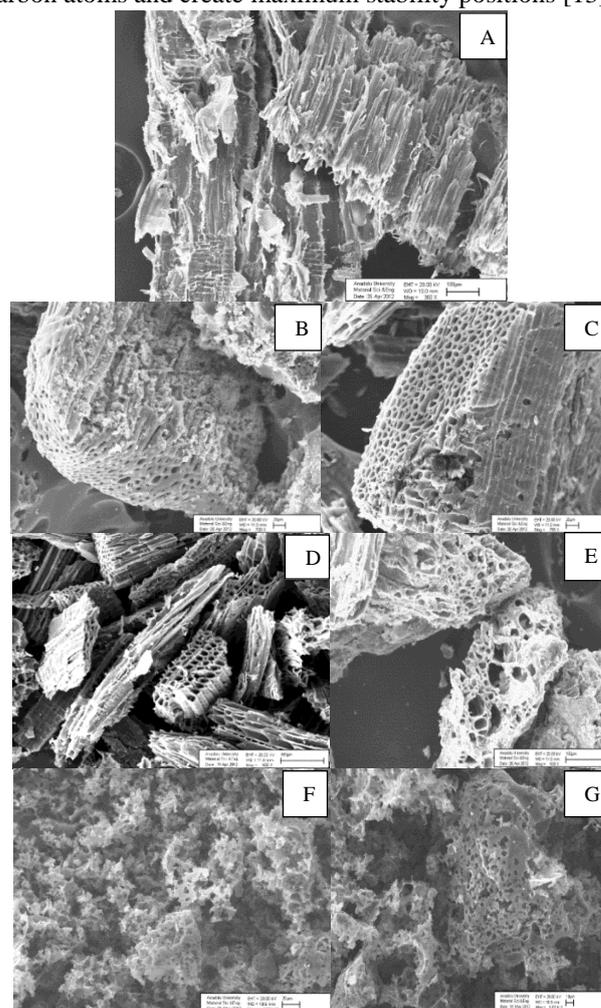


Fig. 1. SEM image of the precursor (A); AC_{ZnCl2} IR:1/1, 500 °C (B), 800 °C (C); AC_{H3PO4} IR:2/1, 500 °C (D), 800 °C (E); AC_{KOH} IR:1/1, 500 °C (F), 700 °C (G)

It can be seen from Fig. 1 that the external surface of the ACs is full of cavities and the pores are of different size and shape, depending on the chemical agent. These cavities result from the evaporation of the chemical reagent during carbonization, leaving a space previously occupied by the chemicals [6], [21].

The result of scanning electron microscopy (SEM) shows that the activated carbon obtained with $ZnCl_2$ activation became a honeycomb structure (Figs. 1B and 1C). Honeycombs have a highly porous structure. Honeycombs in the structure of the activated carbon are monolithic structures without any binders and thus have very great strength, high chemical durability and high electrical conductivity [20].

In the activation of H_3PO_4 , a decrease in surface area with a further increase in temperature might be associated with a sintering effect at high temperature, followed by shrinkage of the carbon or pore coalescence (Figs. 1D and 1E) [22]. This is consistent with the change of the Bet surface areas of the ACs.

The SEM images of AC_{KOH} , are shown in Figs. 1F and 1G. Activation at 800 °C with KOH results in the external surface of the activated carbon being full of cavities, voids and many small pores.

As the carbonization temperature increases, the retention time increases. Activation with $ZnCl_2$ and KOH need a longer retention time than that of the H_3PO_4 to enhance porosity as well as to clear any blocked pore entrances [22].

IV. CONCLUSION

High surface area and high micropore volume activated carbons can be prepared from poplar sawdust by chemical activation. Evolution of surface area during carbonization and activation processes is associated with the effects of the carbonization and the chemicals used. The maximum surface areas were observed with activated carbons prepared by $ZnCl_2$ and by H_3PO_4 activation. AC morphology was directly dependent on the activation mechanism. The surface area was obtained with the pores which were mainly microporous in the samples activated chemically. It is noteworthy that the surface characteristics of the activated carbon samples are very high S_{BET} surface areas and large values of micro volumes. ACs would be a good adsorbent in adsorption application from solution. This observation is supported by the textural characteristics of ACs. It can be concluded that poplar sawdust is a good precursor in the preparation of activated carbon.

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REFERENCES

[1] R. Fonseca-Correa, L. Giraldo and J.C. Moreno-Piraján, "Trivalent chromium removal from aqueous solution with physically and chemically modified corncob waste," *J. Anal. Appl. Pyrolysis*. vol. 101, pp. 132-141, 2013.

[2] Y. Wang, Y. Hu, X. Zhao, S. Wang and G. Xing, "Comparisons of Biochar Properties from Wood Material and Crop Residues at Different Temperatures and Residence Times," *Energy Fuel*. Vol. 27, pp. 5890–5899, 2013.

[3] Q.H. Lin, H. Cheng and G.Y. Chena, "Preparation and characterization of carbonaceous adsorbents from sewage sludge using a pilot-scale microwave heating equipment," *J. Anal. Appl. Pyrolysis*, vol. 93, pp. 113-119, 2012.

[4] T.H. Liou, "Development of mesoporous structure and high adsorption capacity of biomass-based activated carbon by phosphoric acid and zinc chloride activation," *Chem. Eng. J.* vol. 158, pp. 129-142, 2010.

[5] A.M. Yuso, B. Rubiob, and M.T. Izquierdo, "Influence of activation atmosphere used in the chemical activation of almond shell on the characteristics and adsorption performance of activated carbons", *Fuel Process. Technol.* Vol. 119, pp. 74-80, 2014.

[6] H. Saygılı, F. Güzel and Y. Onal, "Conversion of grape industrial processing waste to activated carbon sorbent and its performance in cationic and anionic dyes adsorption," *J. Cleaner Product.* Vol. 93, pp. 84-93, 2015.

[7] N.M. Haimour, and S. Emeish, "Utilization of date stones for production of activated carbon using phosphoric acid," *Waste Manage.* Vol. 2, pp.651-660, 2006.

[8] M.K.B. Gratuito, T. Panyathanmaporn, R.-A. Chumnanklang, N. Sirinuntawittaya, and A. Dutta, "Production of activated carbon from coconut shell: Optimization using response surface methodology," *Bioresource Technol.* Vol. 137, pp. 462-470, 2008.

[9] R. Rostamian, M. Heidarpour, S.F. Mousavi, and M. Afyuni, "Characterization and Sodium Sorption Capacity of Biochar and Activated Carbon Prepared from Rice Husk," *J. Agr. Sci. Tech.* Vol. 17, pp. 1057-1069, 2015.

[10] R. Bodirlau, and C.A. Teaca, "Fourier Transform Infrared Spectroscopy and Thermal Analysis of Lignocellulose Fillers Treated with Organic Anhydrides". *Rom. Journ. Phys.* Vol. 54, pp. 93-104, 2009.

[11] P. Khanra, T. Kuila, N.H. Kim, S.H. Bae, D-S. Yu, and J.H. Lee, "Simultaneous bio-functionalization and reduction of graphene oxide by baker's yeast," *Chem. Eng. J.* vol. 18, pp.526-533, 2012.

[12] S. Kloss, F. Zehetner, A. Dellantonio, R. Hamid, F. Ottner, V. Liedtke, M. Schwanninger, M.H. Gerzabek, and G. Soja, "Characterization of Slow Pyrolysis Biochars: Effects of Feedstocks and Pyrolysis Temperature on Biochar Properties," *J. Environ. Qual.* Vol. 41, pp. 990-1000, 2012.

[13] H. Marsh and F. Rodríguez-Reinoso, "Activated Carbon", 1st ed. U.K.: Elsevier Science, 2006, ch 6, pp. 324-327.

[14] Y. Chen, S-R. Zhai, N. Liu, Y. Song, Q-D. An, and X-W. Song, "Dye removal of activated carbons prepared from NaOH-pretreated rice husks by low-temperature solution-processed carbonization and H_3PO_4 activation," *Bioresource Technol.* Vol. 144, pp. 401–409, 2013.

[15] C. Yuhan, W. Qilin, P. Ning, G. Jinghua, and P. Ding, "Rayon-based activated carbon fibers treated with both alkali metal salt and Lewis acid," *Micropor. Mesopor. Mat.* Vol. 109 pp. 138–146, 2008.

[16] M.M.S. Ali, N. El-Sai, and B.S. Girgis, "Evaluation and Modeling of High Surface Area Activated Carbon from Date Frond and Application on Some Pollutants," *International Journal of Computational Engineering Research* vol. 4, pp. 70-78, 2014.

[17] G.H. Oh, C.H. Yun, and C.R. Park, "Role of KOH in the One-Stage KOH Activation of Cellulosic Biomass," *Carbon Sci.* vol. 4, pp. 180–184, 2003.

[18] D. Lozano-Castello M.A. Lillo-Rodenas, D. Cazorla-Amoros, and A. Linares-Solano, "Preparation of activated carbons from Spanish Anthracite I. Activation by KOH," *Carbon* vol. 39, pp.741–749, 2001.

[19] D. Çuhadaroğlu, and O.A. Uygun, "Production and characterization of activated carbon from a bituminous coal by chemical activation," *African Journal of Biotechnology.* Vol. 20, pp.3703-3710, 2008.

[20] K.P. Gadkaree, and M. Jaroniec, "Pore structure development in activated carbon honeycombs," *Carbon* vol. 38, pp. 983-993, 2000.

[21] R.H. Hesas, A. Arami-Niya, W.M.A. Wan Daud, and J.N. Sahu "Preparation and characterization of activated carbon from apple waste by microwave-assisted phosphoric acid activation: application in methylene blue adsorption," *Bioresources* vol. 8, pp. 2950-2966, 2013.

[22] K. Mohanty, J. Mousam C. Meikap, and M.N. Biswas, "Preparation and Characterization of Activated Carbons from Terminalia Arjuna Nut with Zinc Chloride Activation for the Removal of Phenol from Wastewater," *Ind. Eng. Chem.Res.* vol. 44, pp. 4128-4138, 2005.



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