

POLYETHYLENE TEREPHTHALATE BASED ACTIVATED CARBON PRODUCTION: PRELIMINARY STUDY ON KOH ACTIVATION WITH MICROWAVE ASSIST

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ABSTRACT: Since the beginning of the plastic age, drinking-bottle waste has been increasing worldwide. Petroleum plastic waste is composed mainly of Polyethyleneterephthalate (PET), which is remained in the environment for a long period, thereby causing significant harm to humans, flora, and fauna. Waste recycling is one of the promising mitigation strategies, being used to reduce the amount of final disposal. This research, a preliminary investigation of activated carbon production conditions from PET bottle waste, was carried out using Fractional Factorial Design (FFD) with 95% confidence level. Starter material PET waste was obtained from a local recycling factory. Crusted and sieved PET was carbonized at 700°C for 1 hr. (called PET-char), then impregnated with potassium hydroxide (KOH) at a designed ratio and heated in a microwave. The production factors included PET-char:KOH ratio (1 and 3 by weight), microwave power (540 and 900 watts), and microwave heating time (10 and 30 mins). It was found that all production factors were significant contributors to the characteristics of PET-based activated carbon (PET-AC). The highest iodine adsorption capacity was found at the condition of 3 by weight, 900 Watts, and 30 mins for ratio, microwave power, and heating time, respectively. PET-AC shown highest iodine adsorption capacity with 1,125.34 mg/g and Brunauer Emmett Teller (BET) surface area with 1,345 m²/g. It was confirmed that PET bottle-based waste can be converted to a highly valuable nanoporous adsorbent.

Keywords: Activated carbon, Polyethyleneterephthalate, Design of experiment, Microwave

1. INTRODUCTION

Activated Carbon (AC) is a black material with high surface area, porosity, and high volume. It can be used as environmental purification, electrochemical energy storage, capacitors, catalyst supporter, separation/purification of gas and liquids, and removal of color and toxic substances in water and drinking water [1-6]. The activated carbon can be made from various raw materials that contain low ash content, high fixed carbon, and low cost, such as coal, coconut and palm shell, wood, bamboo, agricultural residues, PVC, and PET bottle waste [7-16]. In case of the increasing capacity of polymer waste, PET is one of the most abundant wastes in multiple levels namely municipal, industrial areas, and ocean [17]. To minimize the issue of PET waste, an interesting solution is converting PET waste, that is negative valued waste, into valuable materials such as activated carbon. It can be used as the starter material for activated carbon production due to its low organic content [18]. PET-based Activated Carbon (PET-AC) provided higher surface area than the commercial activated carbon [19].

Activated carbon preparation can be performed by utilizing two different methods: physical activation (CO₂ or steam) and chemical activation

(KOH, ZnCl₂, HNO₃, and NaOH) [20-23]. Typically, the surface area of PET-based activated carbon by chemical activation is higher than physical activation. Conventional heating using physical activation (CO₂ and steam) provided a surface area of 1,100 - 2,831 m²/g [19,24-27], while for chemical activation, it was 1,200 - 2,900 m²/g [28-31]. Using a convention furnace at high temperature, for a long duration of heating of about 1 to 5 h [15,24,29,32], and high energy consumption resulted in non-uniform porosity of the activated carbon [5,33]. This is a result of the heat transferred from the surface to the inside of the materials, with thermal gradient from high temperature surface to the interior until steady state [34-36]. Recently, a method that has been prominent is microwave irradiation because of its shorter activation time (10–20 mins) [37-40] and low energy consumption [41]. Moreover, this method is able to reduce the non-uniform porosity to solve the present problems. The microwave heats the molecular level of materials by dipole rotation and ionic conduction [42,43].

This research aimed to preliminarily investigate the optimum production conditions of PET-based activated carbon by KOH activation using microwave heating.

2. METHODOLOGY

2.1 PET-char Preparation

The PET bottle's waste was washed and crushed to 1 - 3 mm and dried at 80°C for 24 h. PET was converted to char to remove volatile matter and increase carbon content before activation. Twenty grams of sieved PET was carbonized at 700°C with a 10°C/min heating rate under nitrogen atmospheres for 1 h. Then, it was cooled at room temperature (25 - 30°C). The remaining black solid material was called PET-char, which was ready for the activation process.

2.2 Experimental Design

Design of Experiment (DOE) via Fractional Factorial Design (FFD) has been used for the investigation of the optimum condition of PET-AC synthesis. FFD optimized the number of experiments, time, and overall process cost [44,45].

The three production factors were PET-char:KOH ratio (1:1 and 1:3 by wt.), microwave power (540 and 900 watts), and microwave heating time (10 and 30 mins) with two levels are showing in Table 1. The production factors were A-ratio, B-microwave power, and C-microwave heating time. The experiment was performed in triplicate with totally 12 experiments.

Table 1 PET-AC production factors and levels

Factors	Code	Level	
		-1	+1
Ratio (by weight)	A	1	3
Microwave power (Watt)	B	540	900
Microwave heating time (min)	C	10	30

2.3 PET-AC Production

The mixture of PET-char and KOH at the designed ratio was placed in a 32 mm diameter vertical quartz tube container and heated in a microwave oven (Magnetron OM75S (31), 2450 MHz) under a nitrogen flow rate of 200 ml/min at the given power and the microwave heating time. Afterward, the activated char was rinsed with hydrochloric acid and washed with hot distilled water until the pH reached neutral. The solid adsorbent was dried at 105°C overnight. The produced activated char was then named PET-based activated carbon (PET-AC). All PET-AC were implemented for its iodine adsorption capacity, in order to determine the optimum production condition using analysis of variance.

2.4 PET-AC Characterization

The iodine adsorption capacity of the obtained PET-AC from all experiments were characterized according to the American Society Testing and Materials (ASTM D4607-86). The surface area, the pore volume and the pore size distribution of the PET-AC were analyzed using nitrogen adsorption/desorption isotherms at -196.15°C (Micro Active for ASAP 2460, Norcross, USA). The surface area was calculated with the Brunauer Emmett Teller theory, and the total pore volume was calculated using the adsorbed N₂ volume at high relative pressure. The surface morphology of PET-AC was taken by scanning electron microscopy (Hitachi SU8030, Tokyo, Japan). The surface function group was presented with the Fourier Transform Infrared (FT-IR, Perkin Elmer System 2000). The carbon, hydrogen, nitrogen, and sulfur contents were determined by the elemental analyzer (LECO CHN628 Series Sulfur, USA).

3. RESULTS AND DISCUSSION

3.1 PET-AC Optimum Production Condition

It was found that at the higher level of all factors, the provided iodine adsorption capacity was at its highest level. The obtaining PET-AC provided high iodine adsorption capacity ranging from 759.38 - 1,125.34 mg/g. The relationship between iodine adsorption capacity and all factors was analyzed in a linear form. The fitness of the model and experimental data was in agreement (R²-adjusted 0.9918 and R²-predicted 0.9866). The R²-adjusted and the R²-predicted are high, indicating that there is a well equation in this model between the experiment data and the model prediction [7, 13, 38, 43]. The iodine adsorption prediction model was obtained from the analysis of the results using Design Expert 11 as shown in Eq. (1). It was indicated that all observed factors, A, B and C are significant (*P*-value less than 0.05). The optimal condition factors were 3 by weight, 900 watts, and 30 mins for ratio, microwave power, and heating time, respectively.

$$\text{Iodine adsorption} = +888.06 + 52.66A + 105.41B + 71.67C \quad (1)$$

The analysis of variance (ANOVA) of iodine adsorption capacity is shown in Table 2. The main effects of each factor show *P*-values < 0.05 representing significant factors. The sum of squares of each factor indicated that it was corresponding to the iodine adsorption capacity of the PET-AC.

The normal plot of residuals for iodine adsorption capacity is plotted in order to investigate

Table 2 Analysis of variance (ANOVA) for fractional factorial design

Source	Sum of squares	df	Mean square	F-value	P-value
Model	2.282E+05	3	76082.71	445.33	< 0.0001
A	33271.64	1	33271.64	194.74	< 0.0001
B	1.333E+05	1	1.333E+05	780.42	< 0.0001
C	61643.37	1	61643.37	360.81	< 0.0001
Pure error	1366.78	8	170.85		
Cor total	2.296E+05	11			

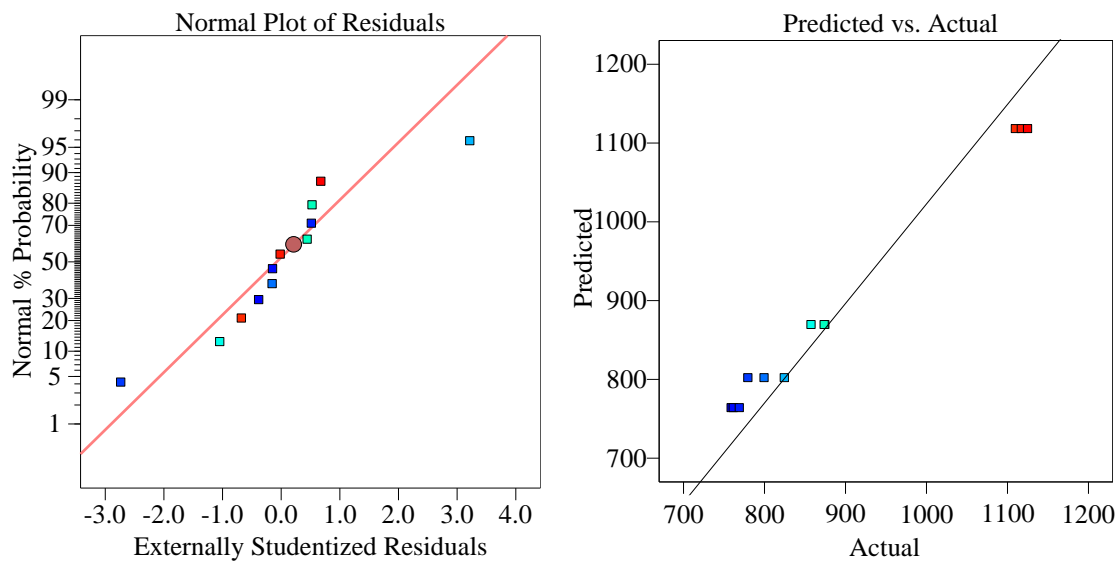


Fig.1 Normal plot of residuals for iodine adsorption capacity (left) and plot of actual response versus predicted response for iodine adsorption capacity (right)

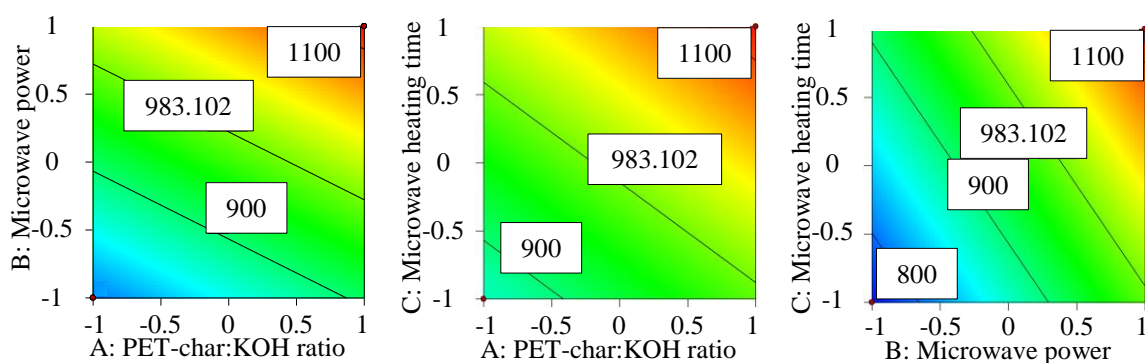


Fig.2 Iodine adsorption capacity contour plot of PET-AC

the normality of data [46-48]. Fig.1 shows well normal distribution residuals data and the predicted (obtained from Eq.1) versus actual plots of iodine adsorption capacity. It indicated that the predicted values agreed well with the actual data, thereby indicating high model ability [7,43,49,50].

The response surface of the combined effect of the overall factors are shown in Fig.2. The iodine adsorption capacity of PET-AC was enhanced with the increase of factor levels due to the improvement in the porosity of the activated carbon.

3.2 PET-AC Characteristics

3.2.1 N_2 adsorption-desorption isotherm

The N_2 adsorption-desorption isotherms of the produced PET-AC indicated type IV with the hysteresis loop (Fig.3) based on the classification isotherm of The International Union of Pure and Applied Chemistry (IUPAC) classification [51,52]. It was demonstrated that PET-AC was mainly mesoporous [15,51-53].

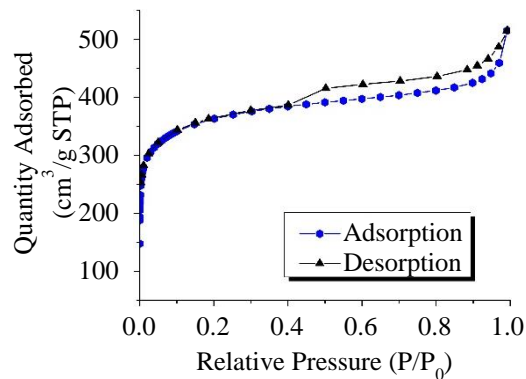


Fig.3 Nitrogen adsorption-desorption isotherm of PET-based activated carbon obtained from the optimum production condition

The pore size distribution of PET-AC is shown in Fig.4. PET-AC achieved the optimum condition with the average pores size of 2.03 nm, the BET surface area of 1,345 m^2/g , and the total pore volume with 0.68 cm^3/g . The obtained PET-AC had a relatively high surface area compared to the previous reports, as shown in Table 3.

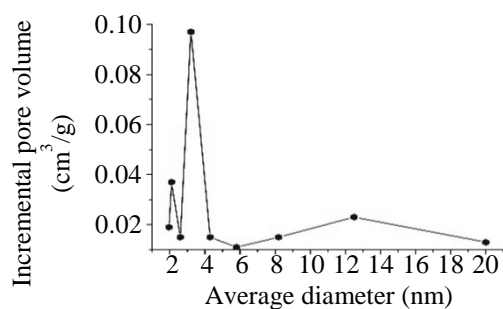


Fig.4 Pore size distribution of PET-AC obtained from the optimum production condition

3.2.2 Physical and chemical characteristics

The SEM morphology of the PET-char and PET-AC gained from the optimum production condition are shown in Fig.5. It can be seen that PET-AC exhibits higher pore distribution than PET-char after the chemical activation by the microwave heating process.

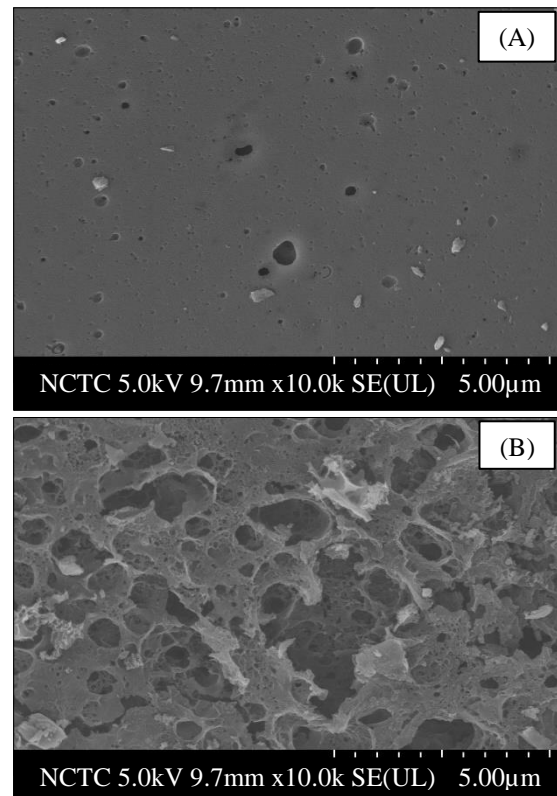


Fig.5 Scanning electron microscopy images of PET-char (A) and PET-AC (B)

The elemental analysis of PET, PET-char and PET-AC are shown in Table 4. It was found that the PET-AC shows a higher carbon content than the PET-char due to the elimination of some amount of oxygen from the materials [39].

The FT-IR spectra of the PET-char and PET-AC are shown in Fig.6. PET waste has large amounts of O-H stretching, CH_3 , CH_2 , CH groups, $C=O$, and aromatic groups [54,55], while this study shown the surface functional groups of PET-char have $C=O$, $C-N$ and $C-Cl$ bonds. Hence, PET-AC shown bands at 1,135 cm^{-1} and 1,496 cm^{-1} , were observed for $C=C$ and $C=O$ in the aromatic and ether structures, respectively, because the others have been removed during the microwave heating process [15,51].

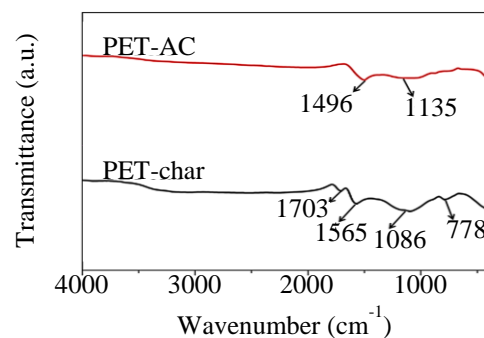


Fig.6 FT-IR spectra of the PET-char and PET-AC

Table 3 Pore structure of different activated carbons

Raw material	Activating agent	Heating method	S _{BET} (m ² /g)	V _T (cm ³ /g)	Reference
PET	KOH	Microwave	1,345	0.68	This work
PET	Steam	furnace	1,170	0.63	[53]
PET	Steam	furnace	1,524	0.60	[26]
PET	CO ₂	furnace	1,850	0.74	[26]
PET	CO ₂	furnace	790	0.43	[15]
PET	CO ₂	furnace	1,110	0.39	[52]

Table 4 Ultimate analysis of PET-based materials

Sample	Ultimate analysis (% dry basis)					Reference
	C	H	O	N	S	
PET	59.62	6.18	34.19	-	0.01	This work
PET-char	55.76	1.43	42.55	0.26	-	This work
PET-AC	80.08	1.45	17.94	0.52	-	This work
PET-50S (steam activation)	96.49	0.42	2.97	0.08	-	[26]
PET-50C (CO ₂ activation)	97.31	0.42	2.21	0.02	-	[26]

4. CONCLUSION

The optimum condition for the preparation of PET-AC was 3 by weight, 900 watts, and 30 mins for the ratio, the microwave power, and the heating time, respectively. The maximum iodine adsorption capacity was 1,125.34 mg/g, and surface area was 1,345 m²/g. It was completed that PET bottle waste can be converted to a highly valuable activated carbon by using KOH and the microwave activation.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

- [1] Kostoglou N., Koczwara C., Prehal C., Terziyska V., Babic B., Matovic B., Constantinides G., Tampaxis C., Charalambopoulou G., Steriotis T., Hinder S., Baker M., Polychronopoulou K., Doumanidis C., Paris O., Mitterer C. and Rebholz C., Nanoporous Activated Carbon Cloth as a Versatile Material for Hydrogen Adsorption, Selective Gas Separation and Electrochemical Energy Storage, Nano Energy, Vol.40, 2017, pp.49-64.
- [2] Xu J., Chen L., Qu H., Jiao Y., Xie J., and Xing G., Preparation and Characterization of Activated Carbon from Reedy Grass Leaves by Chemical Activation with H₃PO₄, Vol.320, 2014, pp.674-680.
- [3] Wigmans T., Industrial Aspects of Production and Use of Activated Carbons, Carbon, Vol.27, No.1, 1989, pp.13-22.
- [4] Lu P.J., Lin H.C., Yu W.T., and Chern J.M., Chemical Regeneration of Activated Carbon Used for Dye Adsorption, J. of the Taiwan Institute of Chemical Engineers, Vol.42, No.2, 2011, pp.305-311.
- [5] Ji Y., Li T., Zhu L., Wang X., and Lin Q., Preparation of Activated Carbons by Microwave Heating KOH Activation, Appl. Surf. Sci., Vol.254, No.2, 2007, pp.506-512.
- [6] Derbyshire F., Jagtoyen M., Andrews R., Rao A., Martin-Gullon I., and Grulke E.A., Carbon Materials in Environmental Applications, Chem. Phys. Carbon, 2001, pp.1-66.
- [7] Gottipati R., and Mishra S., Process Optimization of Adsorption of Cr(VI) on Activated Carbons Prepared from Plant Precursors by a Two-Level Full Factorial Design, Chem. Eng. J., Vol.160, No.1, 2010, pp.99-107.
- [8] Yang S., Hu H., and Chen G., Preparation of Carbon Adsorbents with High Surface Area and a Model for Calculating Surface Area, Carbon, Vol.40, No.3, 2002, pp.277-284.

- [9] Promdee K., Chanvidhwatanakit J., Satitkune S., Boonmee C., Kawichai T., Jareenprasert S., and Vitidsant T., Characterization of Carbon Materials and Differences from Activated Carbon Particle (ACP) and Coal Briquettes Product (CBP) Derived from Coconut Shell via Rotary Kiln, *Renew. Sust. Energ. Rev.*, Vol.75, 2017, pp.1175-1186.
- [10] Su W., Zhou L., and Zhou Y., Preparation of Microporous Activated Carbon from Raw Coconut Shell by Two-Step Procedure1 Supported by the National Natural Science Foundation of China (No.20336020), *Chinese Journal of Chemical Engineering*, Vol.14, No.2, 2006, pp.266-269.
- [11] Wang T., Tan S. and Liang C., Preparation and Characterization of Activated Carbon from Wood via Microwave-Induced ZnCl_2 Activation, *Carbon*, Vol.47, No.7, 2009, pp.1880-1883.
- [12] Chen Z., Deng S., Wei H., Wang B., Huang J., and Yu G., Activated Carbons and Amine-Modified Materials for Carbon Dioxide Capture — a Review, *Front. Environ. Sci. Eng.*, Vol.7, No.3, 2013, pp.326-340.
- [13] Xin H.D., Srinivasakannan C., Qu W.W., Xin W., Jin H.P., and Li B.Z., Regeneration of Microwave Assisted Spent Activated Carbon: Process Optimization, Adsorption Isotherms and Kinetics, *Chem. Eng. Process.*, Vol.53, 2012, pp.53-62.
- [14] Qiao W.M., Yoon S.H., Korai Y., Mochida I., Inoue S., Sakurai T., and Shimohara T., Preparation of Activated Carbon Fibers from Polyvinyl Chloride, *Carbon*, Vol.42, No.7, 2004, pp.1327-1331.
- [15] Esfandiari A., Kaghazchi T., and Soleimani M., Preparation and Evaluation of Activated Carbons Obtained by Physical Activation of Polyethyleneterephthalate (PET) Wastes, *J. of the Taiwan Institute of Chemical Engineers*, Vol.43, No.4, 2012, pp.631-637.
- [16] Mendoza C.R., Cuerda E.M., Alexandre F.M.F., Fernández G.C., and Gómez S.V., Preparation of High-Quality Activated Carbon from Polyethyleneterephthalate (PET) Bottle Waste. Its Use in the Removal of Pollutants in Aqueous Solution, *J. of Environmental Management*, Vol.181, 2016, pp.522-535.
- [17] Scudamore M., Briggs P., and Prager F., Cone Calorimetry—a Review of Tests Carried Out on Plastics for the Association of Plastic Manufacturers in Europe, *Fire Mater.*, Vol.15, No.2, 1991, pp.65-84.
- [18] László K., Adsorption from Aqueous Phenol and Aniline Solutions on Activated Carbons with Different Surface Chemistry, *Colloids Surf. Physicochem. Eng. Aspects*, Vol.265, No.1, 2005, pp.32-39.
- [19] Tamon H., Nakagawa K., Suzuki T., and Nagano S., Improvement of Mesoporosity of Activated Carbons from PET by Novel Pre-treatment from Steam Activation, *Vol.37*, 1999, pp.1643–1645.
- [20] Xiao X., Liu D., Yan Y., Wu Z., Wu Z., and Cravotto G., Preparation of Activated Carbon from Xinjiang Region Coal by Microwave Activation and Its Application in Naphthalene, Phenanthrene, and Pyrene Adsorption, *J. of the Taiwan Institute of Chemical Engineers*, Vol.53, 2015, pp.160-167.
- [21] Shim J.W., Park S.J., and Ryu S.K., Effect of Modification with HNO_3 and NaOH on Metal Adsorption by Pitch-Based Activated Carbon Fibers, *Carbon*, 39, No.11, 2001, pp.1635-1642.
- [22] Wu F.C., and Tseng R.L., High Adsorption Capacity NaOH -Activated Carbon for Dye Removal from Aqueous Solution, *J. of Hazardous Materials*, Vol.152, No.3, 2008, pp.1256-1267.
- [23] Otowa T., Nojima Y., and Miyazaki T., Development of KOH Activated High Surface Area Carbon and Its Application to Drinking Water Purification, *Carbon*, Vol.35, No.9, 1997, pp.1315-1319.
- [24] Bratek W., Świątkowski A., Pakuła M., Biniak S., Bystrzejewski M. and Szmigielski R., Characteristics of Activated Carbon Prepared from Waste PET by Carbon Dioxide Activation, *J. of Analytical and Applied Pyrolysis*, Vol.100, 2013, pp.192-198.
- [25] Nakagawa K., Namba A., Mukai S.R., Tamon H., Ariyadejwanich P., and Tanthapanichakoon W., Adsorption of Phenol and Reactive Dye from Aqueous Solution on Activated Carbons Derived from Solid Wastes, *Water Res.*, Vol.38, No.7, 2004, pp.1791-1798.
- [26] Lorenc G.E., Diez M.A., and Gryglewicz G., Influence of Pore Size Distribution on the Adsorption of Phenol on PET-Based Activated Carbons, *J. of Colloid and Interface Science*, Vol.469, 2016, pp.205-212.
- [27] Domingo G.M., Fernández J.A., Almazán A.M.C., López G.F.J., Stoeckli F., and Centeno T.A., Poly(ethylene terephthalate)-Based Carbons as Electrode Material in Supercapacitors, *J. of Power Sources*, Vol.195, No.12, 2010, pp.3810-3813.
- [28] Lian F., Chang C., Du Y., Zhu L., Xing B., and Liu C., Adsorptive Removal of Hydrophobic Organic Compounds by Carbonaceous Adsorbents: A Comparative Study of Waste-Polymer-Based, Coal-Based Activated Carbon, and Carbon Nanotubes, *J. of Environmental Sciences*, Vol.24, No.9, 2012, pp.1549-1558.
- [29] Lian F., Xing B., and Zhu L., Comparative Study on Composition, Structure, and Adsorption Behavior of Activated Carbons

- Derived from Different Synthetic Waste Polymers, *J. of Colloid and Interface Science*, Vol.360, No.2, 2011, pp.725-730.
- [30] de Paula F.G., de Castro M.C., Ortega P.F., Blanco C., Lavall R.L., and Santamaría R., High Value Activated Carbons from Waste Polystyrene Foams, *Microporous Mesoporous Mater.*, Vol.267, 2018, pp.181-184.
- [31] Nakagawa K., Tamon H., Suzuki T., and Nagano S., Improvement of Mesoporosity of Activated Carbons from PET by Novel Pre-Treatment for Steam Activation, in *Adsorption Science and Technology*, World Scientific, 2000, pp.456-460.
- [32] Sych N.V., Kartel N.T., Tsyba N.N., and Strelko V.V., Effect of Combined Activation on the Preparation of High Porous Active Carbons from Granulated Post-Consumer Polyethyleneterephthalate, *Appl. Surf. Sci.*, Vol.252, No.23, 2006, pp.8062-8066.
- [33] Zhong Z.Y., Yang Q., Li X.M., Luo K., Liu Y., and Zeng G.M., Preparation of Peanut Hull-Based Activated Carbon by Microwave-Induced Phosphoric Acid Activation and Its Application in Remazol Brilliant Blue R Adsorption, *Ind. Crops. Prod.*, Vol.37, No.1, 2012, pp.178-185.
- [34] Thostenson E.T., and Chou T.W., Microwave Processing: Fundamentals and Applications, *Compos. Part A Appl. Sci. Manuf.*, Vol.30, No.9, 1999, pp.1055-1071.
- [35] Xin H.D., Srinivasakannan C., Jin H.P., Li B.Z., and Zheng Y.Z., Comparison of Activated Carbon Prepared from Jatropha Hull by Conventional Heating and Microwave Heating, *Biomass Bioenergy*, Vol.35, No.9, 2011, pp.3920-3926.
- [36] Foo K.Y., and Hameed B.H., Preparation and Characterization of Activated Carbon from Pistachio Nut Shells via Microwave-Induced Chemical Activation, *Biomass Bioenergy*, Vol.35, No.7, 2011, pp.3257-3261.
- [37] Wang X., Liang X., Wang Y., Wang X., Liu M., Yin D., Xia S., Zhao J., and Zhang Y., Adsorption of Copper (II) onto Activated Carbons from Sewage Sludge by Microwave-Induced Phosphoric Acid and Zinc Chloride Activation, *Desalination*, Vol.278, No.1, 2011, pp.231-237.
- [38] Hoseinzadeh H.R., Arami N.A., Wan D.W.M.A., and Sahu J.N., Preparation of Granular Activated Carbon from Oil Palm Shell by Microwave-Induced Chemical Activation: Optimisation Using Surface Response Methodology, *Chem. Eng. Res. Des.*, Vol. 91, No.12, 2013, pp.2447-2456.
- [39] Liu Q.S., Zheng T., Wang P., and Guo L., Preparation and Characterization of Activated Carbon from Bamboo by Microwave-Induced Phosphoric Acid Activation, *Ind. Crops. Prod.*, Vol.31, No.2, 2010, pp.233-238.
- [40] Deng H., Yang L., Tao G., and Dai J., Preparation and Characterization of Activated Carbon from Cotton Stalk by Microwave Assisted Chemical Activation—Application in Methylene Blue Adsorption from Aqueous Solution, *J. of Hazardous Materials*, Vol.166, No.2, 2009, pp.1514-1521.
- [41] Yuen F.K., and Hameed B.H., Recent Developments in the Preparation and Regeneration of Activated Carbons by Microwaves, *Adv. Colloid Interface Sci.*, Vol.149, No.1, 2009, pp.19-27.
- [42] Liu Q.S., Zheng T., Li N., Wang P., and Abulikemu G., Modification of Bamboo-Based Activated Carbon Using Microwave Radiation and Its Effects on the Adsorption of Methylene Blue, *Appl. Surf. Sci.*, Vol.256, No.10, 2010, pp.3309-3315.
- [43] Xin H.D., Srinivasakannan C., Jin H.P., Li B.Z., and Zheng Y.Z., Preparation of Activated Carbon from Jatropha Hull with Microwave Heating: Optimization Using Response Surface Methodology, *Fuel Process. Technol.*, Vol.92, No.3, 2011, pp.394-400.
- [44] Kavak D., Removal of Boron from Aqueous Solutions by Batch Adsorption on Calcined Alunite Using Experimental Design, *J. of Hazardous Materials*, Vol.163, No.1, 2009, pp.308-314.
- [45] Öztürk N., and Kavak D., Boron Removal from Aqueous Solutions by Adsorption on Waste Sepiolite and Activated Waste Sepiolite Using Full Factorial Design, *Adsorption*, Vol.10, No.3, 2004, pp.245-257.
- [46] Cleveland W.S., *Visualizing Data*, Hobart Press Summit, NJ, Vol.2, 1993.
- [47] Nelson W., and Dognanksoy N., Computer Program Pownor for Fitting the Power-Normal and-Lognormal Models to Life or Strength Data from Specimens of Various Sizes, *NASA STI/Recon Tech. Rep. N.*, Vol.92, 1992.
- [48] Wilk M.B., and Gnanadesikan R., Probability Plotting Methods for the Analysis for the Analysis of Data, *Biometrika*, Vol.55, No.1, 1968, pp.1-17.
- [49] Danish M., Khanday W.A., Hashim R., Sulaiman N.S.B., Akhtar M.N., and Nizami M., Application of Optimized Large Surface Area Date Stone (*Phoenix Dactylifera*) Activated Carbon for Rhodamin B Removal from Aqueous Solution: Box-Behnken Design Approach, *Ecotoxicol. Environ. Saf.*, Vol.139, 2017, pp.280-290.
- [50] Annadurai G., Juang R.S., and Lee D.J., Factorial Design Analysis for Adsorption Of Dye on Activated Carbon Beads Incorporated

- with Calcium Alginate, *Adv. Environ. Res.*, Vol.6, No.2, 2002, pp.191-198.
- [51] Bansal R.C., and Goyal M., *Activated Carbon Adsorption*, CRC press, 2005.
- [52] Sing K.S.W., *Reporting Physisorption Data for Gas/Solid Systems with Special Reference to the Determination of Surface Area and Porosity (Recommendations 1984)*, *Pure Appl. Chem.*, Vol.57, No.4, 1985, pp.603.
- [53] László K., and Szűcs A., *Surface Characterization of Polyethyleneterephthalate (PET) Based Activated Carbon and the Effect of pH on Its Adsorption Capacity from Aqueous Phenol and 2,3,4-Trichlorophenol Solutions*, *Carbon*, Vol.39, No.13, 2001, pp.1945-1953.
- [54] Pereira A.P.d.S., Silva M.H.P.d., Lima J.É.P., Paula A.D.S., and Tommasini F.J., *Processing and Characterization of PET Composites Reinforced with Geopolymer Concrete Waste*, *J. of Materials Research*, Vol.20, 2017, pp.411-420.
- [55] Torres H.A., Del A.D., Domínguez C.M.A., Palma R.D., Perales C.M., and Flores V.A., *Morphological and Mechanical Properties Dependence of PLA Amount in PET Matrix Processed by Single-Screw Extrusion*, *Polym. Plast. Technol. Eng.*, Vol.55, 2016, pp.672-683.

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