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Production and characterization of activated carbon from pineapple waste for treatment of kitchen wastewater

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ABSTRACT

Dried and grounded pineapple peel and crown waste materials were carbonized at 270°C and activated with H_3PO_4 and $ZnCl_2$ at an impregnation ratio of 1:1. The activated carbon (AC) characteristics were investigated based on their yield, moisture and ash content, volatile matter and bulk densities. Also, their surface morphology and functional groups were analyzed using scanning electron microscopy (SEM), Brunauer–Emmett–Teller, Barrett–Joyner–Halenda analysis and Fourier transform infrared, respectively. Biochemical oxygen demand (BOD), total dissolved oxygen (TDS), pH and turbidity were tested before and after the treatment of kitchen wastewater. The results from various pollution contaminant indicators demonstrate the effect of contact time in the reduction of pH, BOD, TDS and turbidity and from observations; an increase in contact time yields an increase in the reduction of all the contaminants indicators tested. H_3PO_4-activated pineapple peel (PPPAC) produce the highest percentage yield and bulk density to be 58.15% and 0.42 g/cm^3 compared to others, based on the physicochemical characterization and investigation of the treated wastewater, PPPAC performed better in the reduction of pH and percentage removal of BOD when compared to $ZnCl_2$-activated pineapple peel (PPZAC), while $ZnCl_2$-activated pineapple crown (PCZAC) performed better in the reduction of pH, and percentage removal of TDS and BOD when compared to H_3PO_4-activated pineapple crown (PCPAC).

Keywords: Activated carbon; Wastewater; Adsorption; Pineapple peel; Zinc chloride; Phosphoric acid

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1. Introduction

Wastewater is from a mixture of domestic, industrial, or agriculture activities, surface runoff or storm water, and sewer inflow or infiltration. It constitutes about 99.0% water and 0.1% nutrients [1]: phosphorous and nitrogen, fats, oils, grease: cooking oils, body lotions, Pathogens: disease-causing bacteria and viruses, biochemical oxygen demand (BOD), etc. Wastewater generated from the kitchen may contain biological load from food preparation [2], washing of utensils in the kitchen, soap, and detergents, with primary toxic substances like proteins, carbohydrates, detergents, oil, and grease, dissolved and suspended solids as listed [2,3]. The kitchen wastewater has food particles, oil, grease and chemicals from dishwashing detergents and these particles can create public health problems like kidney stones, cardiovascular disorder and skin stretching [4]. These can be prevented by effectively eliminating the pollutants using

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chemically activated carbon, and the treated water can be used for an agricultural or gardening purpose, if oxidized, can also be used for rearing fishes [1,5]. One of the most desired adsorbents above others is the activated carbon because of its easy accessibility and great surface area. However, the high cost of operation and problems in regenerating activated carbon causes several researchers to look for other economic adsorbents [6].

ACs is the most notable adsorbents known for wastewater treatment [1,5,7]. It is a common carbonaceous resource. One of the properties of AC is that of its porous structure and large surface area. AC captures the targeted components for removal, rendering the water sufficient for discharge or reuse. AC is widely used to adsorb natural organic compounds, purify, color removal, recuperate and remove odors at low cost and greater efficiency [4,8].

ACs work on adsorption principle. Adsorption is an interfacial process that involves the collection of gaseous or solute components on the surface of adsorbent solids; this process is called Van-der-Waals forces [1,9]. The type of AC, the particle size, the pore size, and its distribution, determines the adsorption power and rate [9].

Adsorption is both the physical and chemical process of accumulating a substance at the interface between liquid and solids phases. Adsorption is a mass transfer process, where materials are gathered at the interface of two phases, for example, liquid–liquid, gas–solid, gas–liquid, liquid–solid and liquid–gas interface. Adsorption is of two types: physical adsorption (physisorption) and chemical adsorption (chemisorption) [1,4,5,9].

Physical adsorptions occur when there is an interaction between the solid surface and the adsorbed molecules. However, if the attractive forces between adsorbed molecules and the solid surface area due to chemical bonding chemical adsorption will occur [10]. Chemical adsorption occurs only as a monolayer, therefore substance chemisorbed on solid surface area tough to be removed due to stronger bonds [11]. Under favorable conditions, chemisorption and physisorption processes can occur concurrently [1,8].

AC used in water treatment applications is granular activated carbon (GAC) and powdered activated carbon (PAC). GAC has a relatively larger particle size compared to PAC and consequently, presents a smaller external surface. These carbons are suitable for adsorption of gases and vapors because they diffuse rapidly [7,9,12]. Over the years, these materials have come to be an imperative area for research because of their outstanding properties, which involve their great precise areas, high porosity, non-toxicity and the ability of their tuneable surface to contain various functional groups [13]. Diversities of raw carbon materials which are used to produce activated carbon are: peat, coal, lignite, Oil carbon are classified as granulated activated carbon; rayon, acrylonitrile, coal tar pitch, petroleum pitch belongs to fibrous activated carbon and biomass properties, for example, bagasse, sawdust, coconut shells and wood [4,6,14].

AC is important in treating wastewater, to purify water for drinking, gas and liquid phase adsorption. Activated carbon has great use in adsorption, which arises from its rapid adsorption, thermal stability and high porosity [15]. AC precursors include the use of agricultural wastes as low-cost raw materials with high carbon substances and low inorganic matter [16–18].

In numerous production procedures, production of very quality activated carbon consists of adjusting the conditions for production to achieve the preferred attributes of the yield [16]. Generally, this adjustment becomes complex as there happens to be more than one characteristic to be measured. Besides, the desirable attributes examine the necessities of the consumers, for instance, high surface area, high porosity, high bulk density and the producer side [1,19]. The higher yield achieved at a lower cost of energy and operation is constantly desired but cautious balancing is highly necessary to abstain from ignoring other qualities [20]. Research shows that the ACs prepared from agricultural waste like coconut shell, cotton stalks, groundnut husk, rice husk, corncob, fluted pumpkin stem waste, etc. have been reported [3,16,21]; however, the production of activated carbon from pineapple peel and crown by a process of chemical activation and its applicability for the elimination of water hardness has not been reported [22]. This study aims to produce and characterize activated carbon from pineapple waste for the treatment of kitchen wastewater.

Extensively, wastewater treatment comprises the following four stages to make the water fit for human utilization: pre-treatment process, primary treatment, secondary treatment and tertiary treatment [23,24]. The pore volume of AC is >0.2 m^3/g, the internal surface area is mostly >400 m^2/g and the size of the pores ranges from 0.3 to a few thousand nanometres. Every activated carbon is categorized by a branched pore framework of various sizes of pores [25,26].

2. Materials and methods

The raw material/precursor used in this research are pineapple peel and pineapple crown. These pineapple parts were subjected to activation using, phosphoric acid (85%), Zinc chloride, distilled water, and deionized water. Phosphoric acid and zinc chloride are of Analar Grades of BDH Laboratory Chemicals (Mirqab – Kuwait City, Kuwait). Distilled and deionized water were from the Chemical Engineering Laboratory of Covenant University.

Drying oven: The drying oven was used in drying the activated carbon, before carbonizing.

Thermo Scientific Thermolyne A1 Premium Muffle Furnace–208 V from the USA: This equipment was used to carbonize the activated carbon.

Digital stopwatch: The stopwatch was used to take reaction/contact time.

Digital weighing balance: The balance was used to weigh the activated carbon, for accuracy during the experiment.

Thermometer: This instrument was used to take and monitor the temperature of the activation process.

Porcelain crucible: The activated carbon was placed in a crucible during the activation process.

Mechanical stirrer: The stirrer was used to ensure a homogeneous mixture of activation.

Mortar and pestle: This was used to grind the activated carbon to powdered form.

Scanning electron microscopy (SEM) model FEI-QUANTA 200: This equipment was used for characterization of the sample.

For Brunauer–Emmett–Teller (BET) analysis, the instrument used includes Micrometrics Gemini 2375 and Gemini V.: The BET instrument was used to determine the pore size of the activated carbon.

The pineapple peel and crown were cut into small pieces, washed and sun-dried for about a week before oven-dried at 110°C for 2 h. The dried pineapple peel and crown are crushed and ground in a ball mill and sieved using 300-micron sieve.

2.1. Preparation of activated carbon (adsorbent)

Oven-dried pineapple crown and peel were then carbonized in a muffle furnace by placing the samples in a crucible at a temperature of 270°C for 1 h each. It was to ensure that little or no oxygen was present during carbonization. The char thus produced was withdrawn from the furnace, cooled to room temperature, and pulverized. Chemical activation was carried out using 1.5 M aqueous solution of phosphoric acid and 1.5 M of zinc chloride by soaking 30 g of the char obtained from the carbonized materials (pineapple peel and pineapple crown) in each solution for 24 h at an impregnation ratio of 1:1 (Weight of carbon to weight of acid) to form a paste. The varying mixtures were filtered and placed in an oven at 105°C for 2 h and allowed to cool at room temperature. The various samples were washed with deionized water followed by 0.1 M hydrochloric acid (HCl) to eliminate any remaining chemical agents. The adsorbents prepared by H_3PO_4 and $ZnCl_2$ were denoted as PPPAC (phosphoric acid-activated pineapple peel), PPZAC (zinc chloride-activated pineapple peel), PCPAC (phosphoric acid-activated pineapple crown), PCZAC (zinc chloride-activated pineapple crown).

2.2. Analysis of the activated carbon

Moisture content was obtained by weighing 1 g of the carbon and placing it in an oven to dry at 110°C for about 2 h. The yield of activated carbon was calculated as the percentage weight of the resultant activated carbon divided by the dried pineapple waste samples. The volatile matter was obtained by measuring 1 g of sample and placed in a closed crucible, heated at 900°C for 7 min in a furnace. Then the covered crucible was cooled to room temperature after several hours and the weight was recorded. Ash content of each adsorbent was determined by measuring each sample and burning in a furnace at 600°C for 1 h. Tapped bulk density of each adsorbent was determined by the tapping procedure. A measured weight of each sample was parked into a 10 mL graduated measuring cylinder. The underneath of the cylinder was tapped mildly on the laboratory bench top several times until there was no visible reduction of the sample level.

Kitchen wastewater used for adsorption study was from Cafeteria 2, Covenant University. Batch mode experiments were carried out using PPPAC, PPZAC, PCPAC, and PCZAC as the adsorbents to investigate a major factor influencing the rate of the extent of reduction of BOD, TSS, pH, total dissolved oxygen (TDS), and turbidity which is contact time. The experiment was carried out by agitating 1 g of each adsorbent with 50 mL of the wastewater at 600 rpm in a 100 mL conical flask for 30, 60, 90, 120, and 180 min. Then the mixture was filtered and the liquid samples are stored for analysis. Other revolutions per minute (rpm) were used for this research, at 300, 400, 500, 700 and 800, respectively only 600 rpm was considered to give the best result based on the adsorbent used.

2.3. Test procedures

2.3.1. BOD test procedures

Specialized 300 mL BOD bottles designed to allow full filling with no air space were being used, of which three bottles were filled with 50 mL of the untreated wastewater sample each while the other bottles were filled with 50 mL of treated wastewater with various contact time using PPPAC, PPZAC, PCPAC and PCZAC each. The BOD concentration is in (mg/L).

2.3.2. pH test procedures

The pH meter was used to determine the pH of wastewater, which was standardized by way of standard solutions provided.

2.3.3. TDS measurement procedures

Wastewater samples were stirred with a magnetic stirrer and 30 mL was measured and drawn with the use of a pipette. The samples were transferred to some set of a clean and pre-weighed evaporating dish. After that period, the evaporating dish was transferred to a desiccator for cooling to ambient temperature for about 15–20 min.

3. Results and discussion

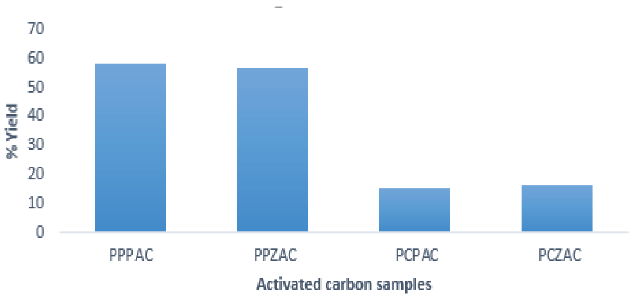


Fig. 1. Percentage yield of AC samples.

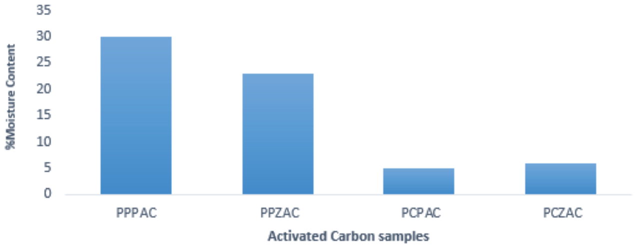


Fig. 2. Percentage moisture content of AC samples.

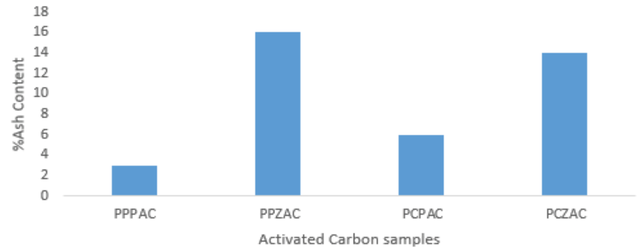


Fig. 3. Percentage ash content of AC samples.

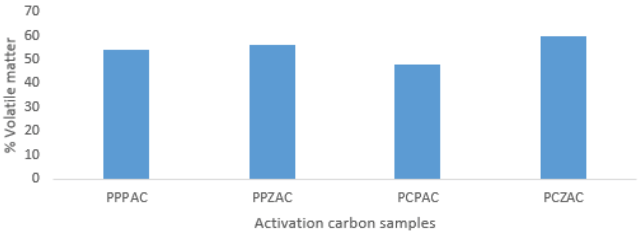


Fig. 4. Percentage volatile matter of AC samples.

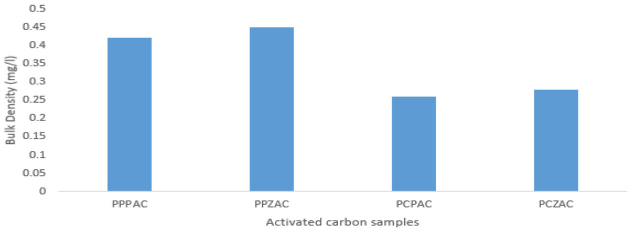
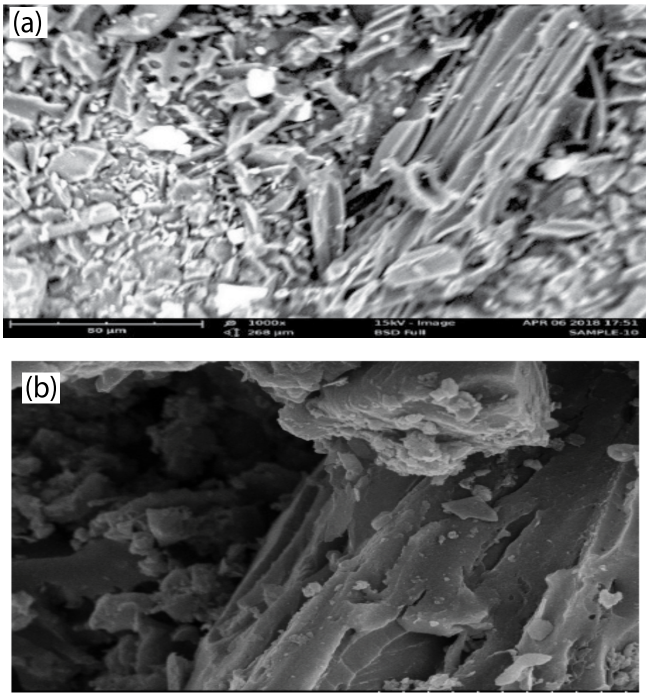


Fig. 5. Tapped bulk density of AC sample.

3.1. Instrumental characterization of AC produced using SEM



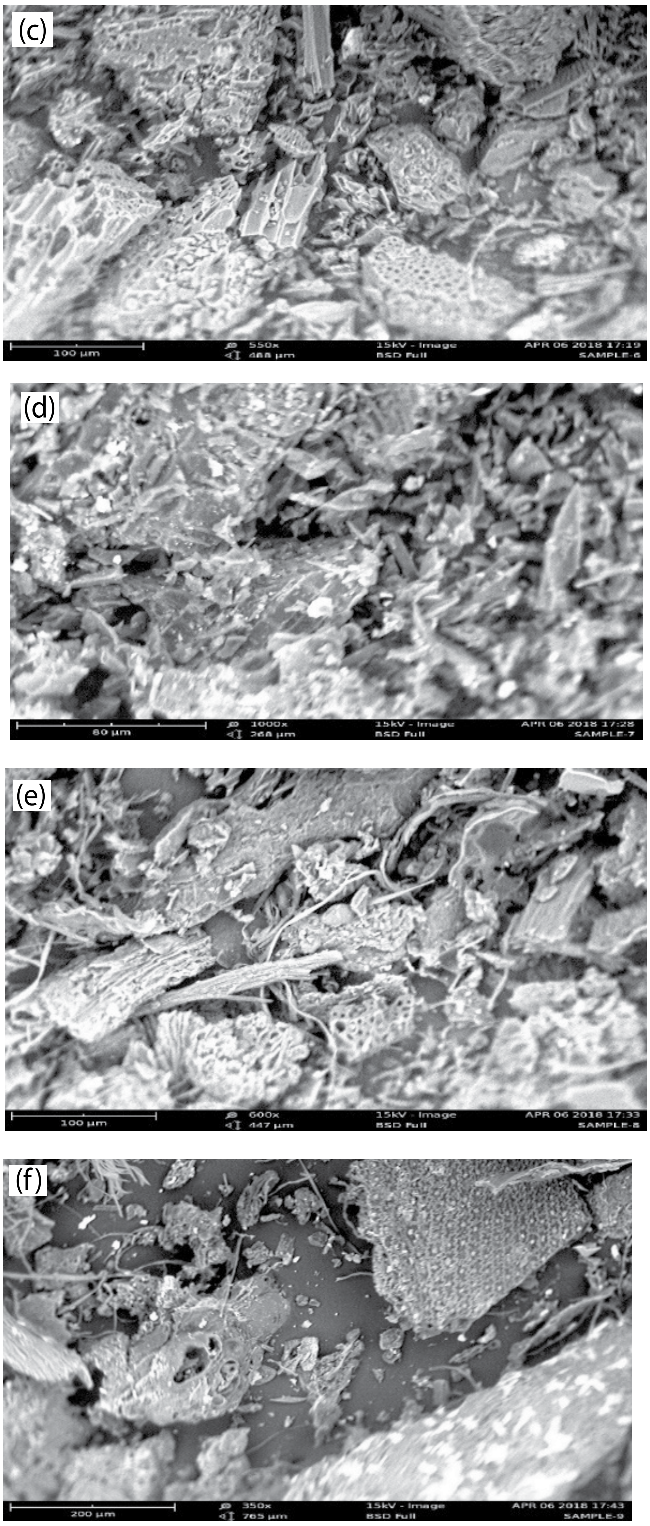


Fig. 6. (a) Carbonized pineapple peel, (b) carbonized pineapple crown, (c) SEM observation of PPPAC, (d) SEM observation of PPZAC, (e) SEM observation of PCPAC, and (f) SEM observation of PCZAC.

3.2. Instrumental characterization of AC produced using Fourier transform infrared spectroscopy

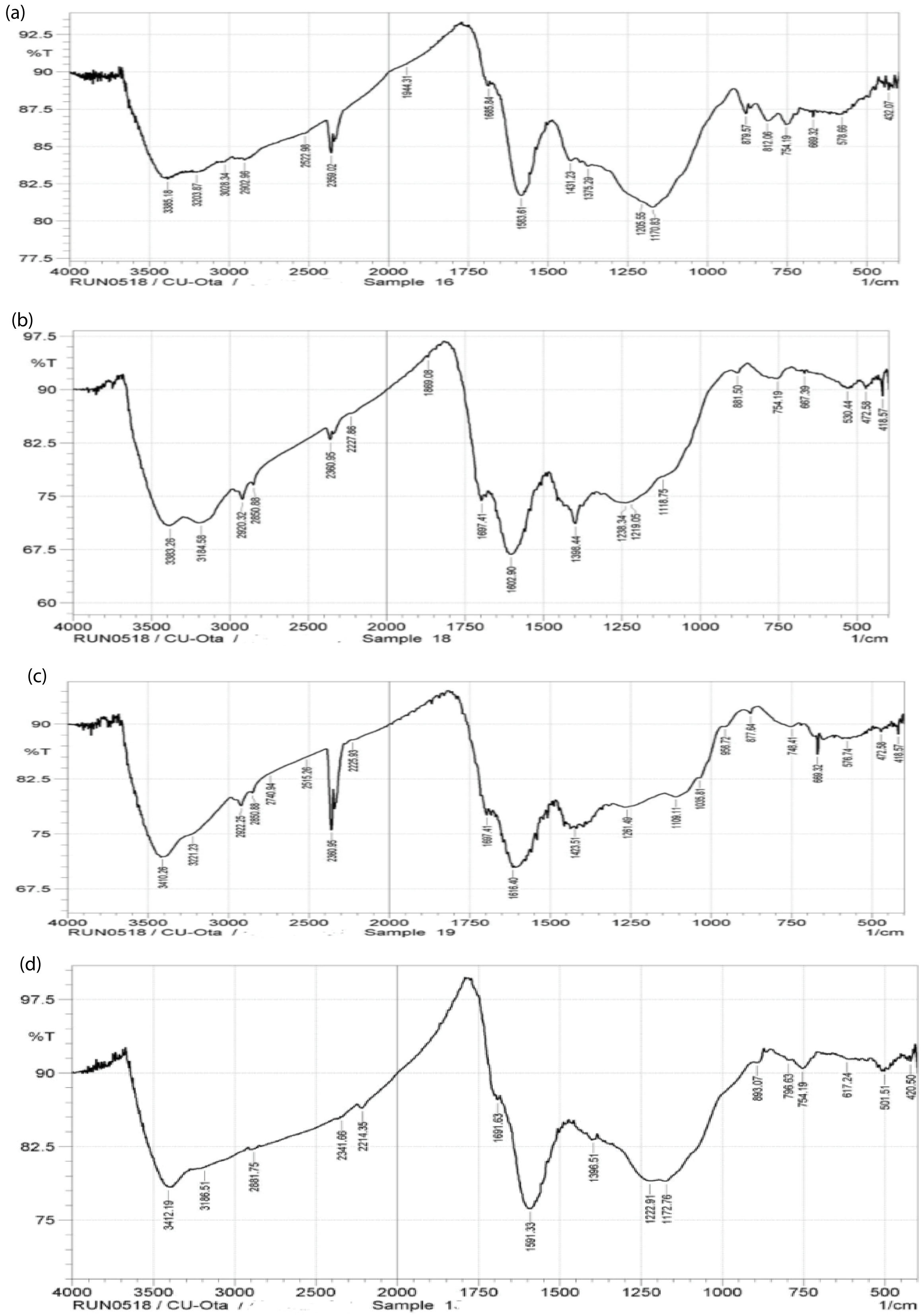


Fig. 7. Fourier transform infrared spectroscopy image of (a) PPPAC, (b) PCPAC, (c) PCZAC, and (d) PPZAC.

PPPAC, PPZAC, PCPAC, and PCZAC were investigated for its effectiveness in the reduction of physicochemical properties such as BOD, TDS, pH, and turbidity from treated Cafeteria 2 wastewater.

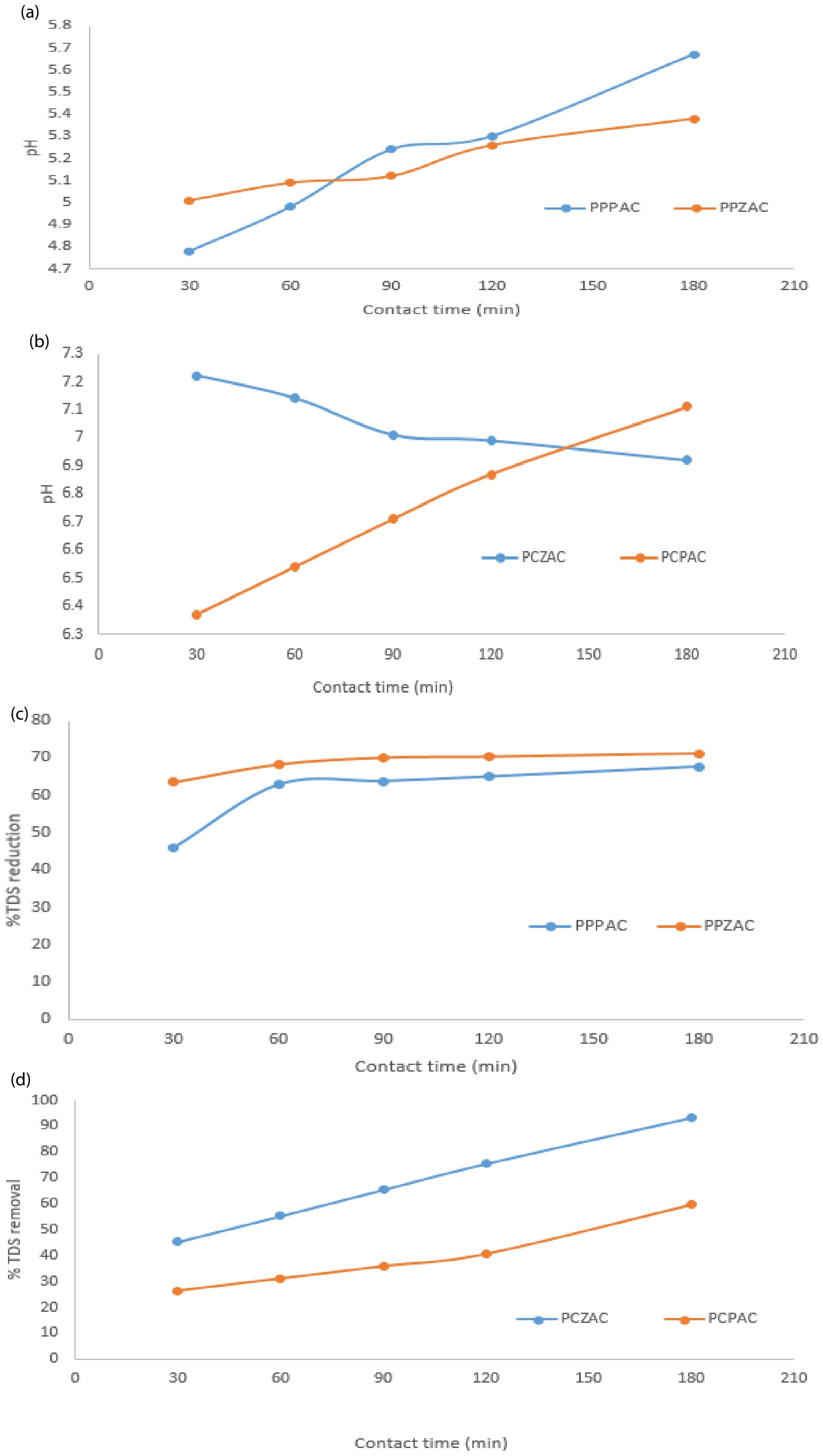


Fig. 8. Continued

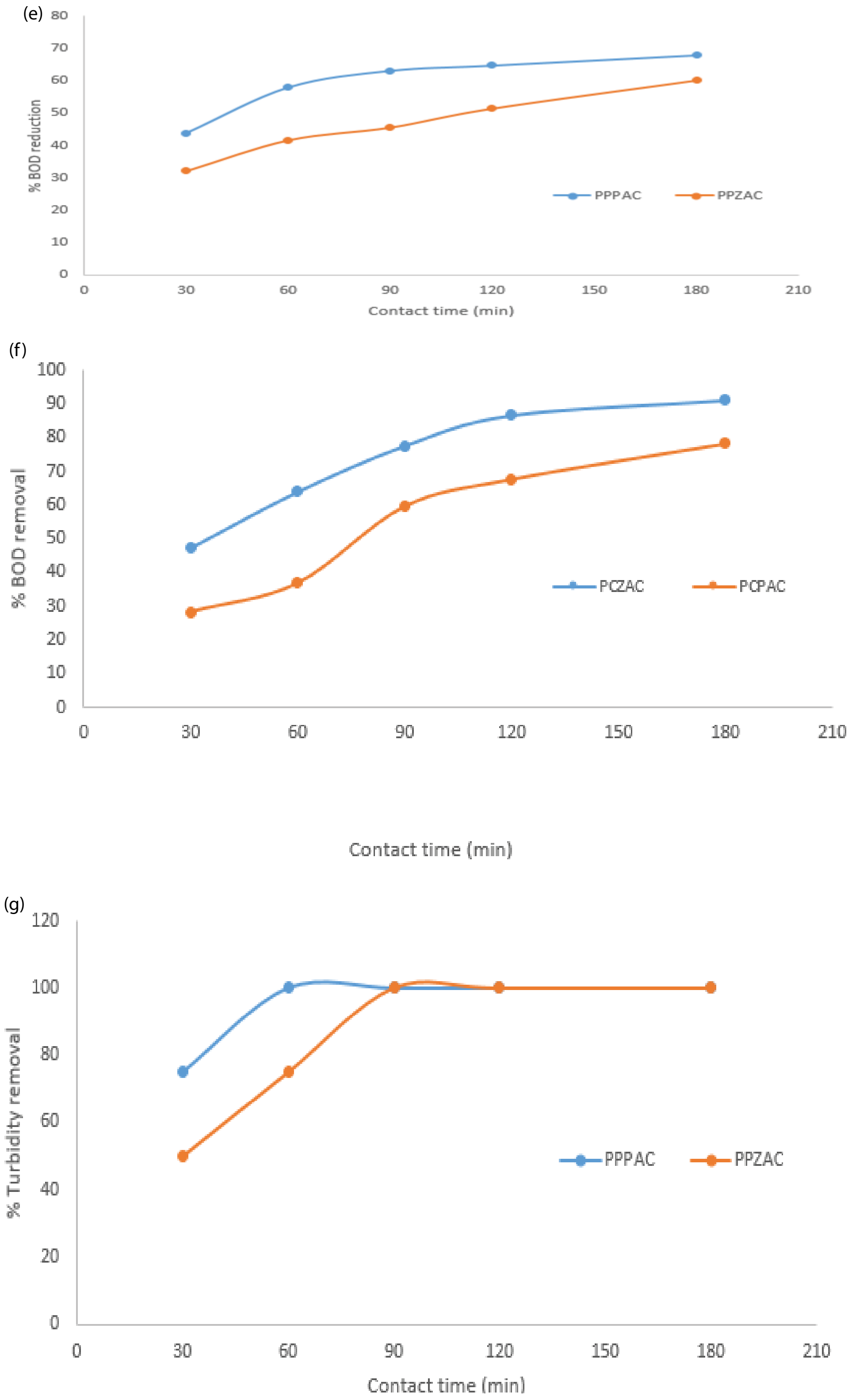


Fig. 8. pH vs. contact time of (a) PPPAC and PPZAC, (b) PCPAC and PCZAC, (c) % TDS removal vs. contact time of PPPAC and PPZAC, (d) % TDS removal vs. contact time of PCZAC and PCPAC, (e) % BOD vs. contact time using PPPAC and PPZAC, (f) % BOD vs. contact time using PCZAC and PCPAC, and (g) Graph of % turbidity removal against varying contact time using PPPAC and PCPAC.

3.3.. BET characterization techniques

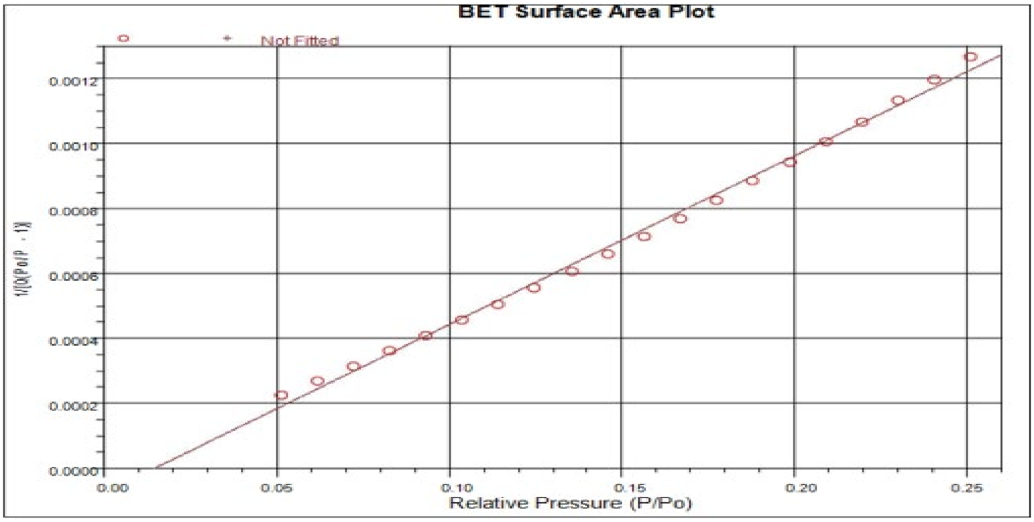


Fig. 9. BET Plot.

3.4. Pore characterization

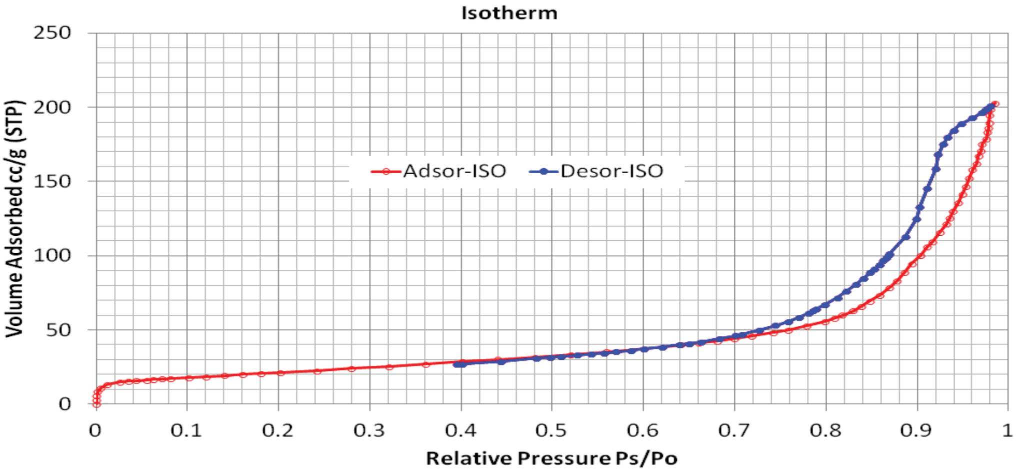


Fig. 10. Isotherm of samples at 270°C.

For yield, activating with zinc chloride and phosphoric acid were performed on different precursors (pineapple peel and crown) for evaluation and comparison. Fig. 1 shows the effect of different activating agents on the yield of AC produced from the pineapple wastes. The activation of pineapple peel using phosphoric acid of 1.5 M concentration, gave the highest yield of 58.15% because it underwent the most efficient dehydration during carbonization. This is also because of the phosphate linkages formed that retain carbon and avoid the high loss of volatile material. Closest to the yield of PPPAC is the yield of PPZAC at 56.88%, due to their similar dehydrating effect on the precursor. Fig. 2 shows that moisture content is extremely high in PPPAC and PPZAC at 30% and 23% respectively, whereas tend to be low in PCPAC and PCZAC at 5% and 6% respectively. The amount of moisture present in prepared Activated Carbons depends on the surface area and pore volume; this means that extensive porosity is introduced by the acid-activation and the chloride-activation on the Pineapple peel especially PPPAC which yielded 30%. Even though moisture content of the carbon has little or no effect on its adsorptive capacity, moisture necessitates the use of the additional weight of carbon during the treatment process. Fig. 3 demonstrates the effect of H_3PO_4 and $ZnCl_2$ on the ash contents of the activated carbon samples from the Pineapple peel and crown. From the results shown in Fig. 3, it shows that the samples were treated with phosphoric acid have less ash content than with zinc chloride. This is due to the formation of phosphate compounds, which increase the volume of the inorganic matter in the activated carbon samples, PPPAC, and PCPAC, thereby increasing the amount of non-ignitable residue left in the furnace. The larger percent ash in the PPZAC and PCZAC samples occur due to excess of the chemical agent within the precursor. Therefore, PCPAC is the most desirable carbon sample because it yielded low ash content and higher carbon content. Fig. 4, indicates that the PCPAC sample is seen to contain the lowest volatile matter having 48% compared to the other samples analyzed, PPPAC, PPZAC, and PCZAC having 54%, 56%, and 60% respectively. PPPAC and PCPAC have the lowest volatile matter percentage because of the phosphoric acid, which formed phosphates and polyphosphate esters with oxygen and hydrogen atoms, which would have emitted as gases during the carbonization process. Bulk Density was affected by the precursor used as well as the degree of activation. From the results of the densities shown in Fig. 5, PPZAC has the highest bulk density to be 0.45 g/mL while PCPAC has the lowest bulk density to be 0.26 g/ml. It can also be observed that chloride-activation of the carbon samples (pineapple peel and crown) yielded higher bulk densities, 0.45 and 0.28 g/mL respectively, compared to the acid-activation of the carbon samples which yielded lower bulk densities, 0.42 and 0.26 g/mL respectively, after the carbonization and activation process. Figs. 6a–f shows the SEM images of the AC samples produced. The micrographs enable the morphological structure of macropores on the surface of the AC samples to be observed. As seen in Figs. 6a and 6b, the micrograph of the carbonized pineapple peel and the crown show that their surfaces barely consists of pores while from the micrographs in Figs. 6c–f, the surface of the AC samples produced shows the presence of pores (macropores). The macropores are formed during activation by phosphoric acid and zinc chloride. From Figs. 6c and 6e, AC samples impregnated with H_3PO_4 clearly show vastly defined pores than AC samples impregnated with $ZnCl_2$ in Figs. 6d and 6f. The pore structures of AC samples produced using different activating agents demonstrate different reaction mechanisms. The mechanism by which phosphoric acid activates an existing carbon is more multifarious and involves the breakdown of the structure followed by gasification by oxygen molecules of phosphates while activation with zinc chloride stimulates the removal of water molecules from lignocellulosic materials which leads to the generation of porosity.

The SEM results show that the surface of H_3PO_4 impregnated pineapple peel in Fig. 8, contains finely honed pores whereby there is a better chance for adsorption into the surface of the pores. The FT-IR spectrum of the activated carbon samples produced from Pineapple peel and pineapple crown prepared using various activating agents in Figs. 7a–d. It provides basic spectra of the carbon samples, especially for the determination of types and intensities of their surface functional groups. Most of the carbon samples exhibit similar infrared spectroscopic characteristics as some of the peaks are explained thus, Figs. 7a–d have strong broad bands at 3,385.18; 3,383.26; 3,410.26; and 3,412.19 cm^{-1} respectively which corresponds to an –OH (hydroxyl) group from phenol and alcohol vibration; saturated aliphatic C–H stretching absorption from 2,850 to 3,000 cm^{-1}. The small bands at about 1,700 cm^{-1} observed in all the samples are assigned to C==O stretching vibrations of aldehydes, lactones, ketones or carboxyl groups. The presence of strong bands at 1,580 to 1,600 cm^{-1} observed in Figs. 7a and d are due to C–C vibrations in aromatic rings; the group of bands present in Figs. 12 and 14 corresponding to –C–H– deformation is characteristic of the alkyl group provided. Broadband appearing between 1,100 and 1,300 cm^{-1} can be seen in all the carbon sample which is usually found with oxidized carbons has being assigned to C–O stretching in acids, phenols, alcohols, ethers, and ester groups, while the peaks around 1,170 to 1,220 cm^{-1} in Figs. 7a, b and d could be as a result of the stretching P=O bond in phosphate ester, O–C bond in P–O–C linkage or P=OOH bond; Alkenyl C=C stretching and peaks in the region 750–890 cm^{-1} present in the Fourier transform infrared spectroscopy (FT-IR) spectra of PPPAC, PPZAC, PCPAC and PCZAC are due to out-of-plane deformation mode of C–H for different substituted benzene rings. During the adsorption process, the ion exchange mechanism occurs between the surface of the adsorbent and the adsorbate. Fig. 8a shows an increase in contact time brought about an increase in pH, while PPPAC yielded the highest pH to be 5.67. The ranges of the values obtained are between 4.8 and 5.67 from both adsorbents. The range gotten from the experiment carried out does not match up to the Federal Environmental Protection Agency (FEPA) standards for pH limits, 6–9 and this can be said to be a result of the high concentration of H_3PO_4 and $ZnCl_2$ used during the activation process. Meanwhile from Fig. 8b the values obtained from treating with PCPAC and PCZAC matches up to the FEPA standards for pH limits by reducing the pH of treated wastewater from 9.41 to a pH ranging from 6–7. Fig. 8b shows a further increase in contact time shows the tendency of yielding towards the FEPA standards for pH limits. Fig. 8c shows that a contact time of 180 min yielded the highest reduction of TDS to be 71.1% and 67.7% for PPZAC and PPPAC respectively. PPZAC is very effective in removing up to 71.1% of the initial TDS present in the kitchen effluent after 180 min. The result indicates that PPZAC achieved a higher adsorption rate of TDS removal during an initial time of 30 min compared to PPPAC. Fig. 8d shows that a contact time of 180 min yielded the highest reduction of TDS to be 59.7% and 93.17% for PCPAC and PCZAC respectively. The results clearly show that PCZAC achieved a higher adsorption rate of TDS removal during an initial time of 30 min with comparison to PCPAC. As the contact time increases, TDS reduction increases and as the treatment time progressed, the adsorbent sites show the tendency towards saturation of the adsorption sites or attainment of equilibrium between the adsorbent and the adsorbate. Fig. 8e indicates that the highest removal percentage of BOD was observed for both PPPAC and PPZAC at the contact time of 180 min. The result shows that PPPAC achieved a higher adsorption rate of BOD removal relative to PPZAC during an initial treatment time of 30 min. Meanwhile from Fig. 8f, the highest percentage removal was achieved for both PCPAC and PCZAC at a treatment time of 180 min, whereby PCPAC yielded a percentage reduction of 78.35% and PCZAC yielded a percentage reduction of 91.04%. The smooth and independent curve points out the development of the monolayer covering of the adsorbate on the exterior surface of the adsorbents. Fig. 8g explains that the optimum percentage removal of turbidity was seen at 100% for both PPPAC and PPZAC at 60 min and 90 min of contact time respectively before attaining equilibrium. The initial turbidity of the kitchen was 8.0 and after contact with the adsorbents, the turbidity of zero (0) was obtained which implies that the treated wastewater is suitable for discharge into the environment, as major pollution contaminants have been reduced.

Figs. 9 and 10 shows the BET and pore characterization techniques. BET analysis gives detailed specific surface area evaluation of materials by nitrogen multilayer adsorption measured as a function of relative pressure using a fully automated analyzer. Single point BET Involves determining specific surface area using a single point on the isotherm and multipoint BET uses a minimum of three data points. The method encompasses external area and pore area evaluations to determine the total specific surface area in m^2/g yielding important information in studying the effects of surface porosity and particle size in several applications. Hence, micropore/mesopore volume and area cannot be obtained from the BET calculations. The micropore volume and area can be estimated.

Barrett–Joyner–Halenda (BJH) method was considered for relatively wide-pore adsorbents with a wide pore size distribution. However, it was repeatedly demonstrated that it can be successfully applied to virtually all types of porous materials. This model is based on the assumption that pores have a cylindrical shape, the pore radius is equal to the sum of the Kelvin radius, and the thickness of the film adsorbed on the pore wall. BJH analysis can be used to determine the pore area and specific pore volume using adsorption and desorption techniques. This technique characterizes pore size distribution independent of the external area due to the particle size of the sample. There are predominantly mesopores and the isotherm is classified as type IV according to International Union of Pure and Applied Chemistry with maximum absorptive volume till 200 cm^3/g.

Results obtained from BET analysis are as follows.

Surface area: Single point surface area at P/P_0 = 0.093958352:993.5784 m^2/g for BET and 848.2342 m^2/g for BJH. BET Adsorption cumulative surface area of pores between 1.7000 and 300.0000 nm diameter gives 136.042 m^2/g. BET pore volume single point adsorption to the total pore volume of pores less than 2.0638 nm diameter at P/P_0 = 0.167431898 gives 0.402173 cm^3/g. BJH adsorption cumulative volume of pores between 1.7000 and 300.0000 nm diameter gives 0.066812 cm^3/g. BET pore size adsorption average pore diameter (4 V/A) gives 1.89206 nm; BJH Adsorption average pore diameter (4 V/A): 1.9645 nm. Micropore volume, micropore area and external surface area obtained are 0.331200 cm^3/g, 673.4308 m^2/g, and 196.8033 m^2/g respectively.

4. Conclusion

Activated carbon produced from pineapple waste for treatment of kitchen wastewater by chemical activation using different activating agents at 270°C, which are phosphoric acid (H_3PO_4) and zinc chloride ($ZnCl_2$). The analysis was carried out on the activated carbon (moisture content volatile matter, ash content and bulk density). Pineapple peel and clown activated with ($ZnCl_2$) and (H_3PO_4) were considered in this study. The activated carbon was characterized using SEM, FT-IR, and BET. The results show significant performance in the reduction of various pollution contaminants such as TDS, BOD, pH, and turbidity. Batch adsorption study was implemented to show the effect of contact time on the reduction of the various contaminants and it was observed from the results obtained that an increase in contact time yields an increase in the reduction of the various contaminants. PPPAC performed better in the reduction of pH and percentage removal of BOD, PCZAC performed better in the reduction of pH, and percentage removal of TDS and BOD.

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References

[1] S.M. Yakout, G. Sharaf El-Deen, Characterization of activated carbon prepared by phosphoric acid activation of olive stones, Arabian J. Chem., 9 (2016) 11–15.

[2] O.G. Abatan, B.A. Oni, A. Agboola, V.E. Efeovbokhan, O. Okiki, Production of activated carbon from African star apple seed husks, oilseed and whole seed for wastewater treatment, J. Cleaner Prod., 232 (2019) 441–450.

[3] V. da Silva Lacerda, J.B. López-Sotelo, A. Correa-Guimarães, Rhodamine B removal with activated carbons obtained from lignocellulosic waste, J. Environ. Manage., 155 (2015) 67–76.

[4] L. Temdrara, A. Addoun, A. Khelifi, Development of olive stones-activated carbons by physical, chemical and physico-chemical methods for phenol removal: a comparative study, Desal. Wat. Treat., 53 (2015) 452–461.

[5] K. Kadirvelu, C. Faur-Brasquet, P. Cloirec, Removal of Cu(II), Pb(II), and Ni(II) by adsorption onto activated carbon cloths, Langmuir, 16 (2015) 8404–8409.

[6] J. Kaźmierczak, P. Nowicki, R. Pietrzak, Sorption properties of activated carbons obtained from corncobs by chemical and physical activation, Adsorption, 19 (2012) 273–281.

[7] V. Dobruskin, Micropore structure of activated carbons and predictions of adsorption equilibrium, Carbon, 40 (2002) 1003–1010.

[8] M. Kubota, A. Hata, H. Matsuda, Preparation of activated carbon from phenolic resin by KOH chemical activation under microwave heating, Carbon, 47 (2009) 2805–2811.

[9] D. Mohan, K. Singh, Single- and multi-component adsorption of cadmium and zinc using activated carbon derived from bagasse—an agricultural waste, Water Res., 36 (2012) 2304–2318.

[10] S. Garg, P. Das, High-grade activated carbon from pyrolytic biochar of Jatropha and Karanja oil seed cakes—Indian biodiesel industry wastes, Biomass Convers. Biorefin., 8 (2018) 545–561.

[11] S. Mopoung, P. Amornsakch, Microporous activated carbon fiber from pineapple leaf fiber by H_3PO_4 activation, Asian J. Sci. Res., 9 (2016) 24–33.

[12] I. Nhapi, Removal of heavy metals from industrial wastewater using rice husks, Open Environ. Eng. J., 4 (2011) 170–180.

[13] E. Yagmur, M. Ozmak, Z. Aktas, A novel method for production of activated carbon from waste tea by chemical activation with microwave energy, Fuel, 87 (2014) 27–32.

[14] J. Rivera-Utrilla, M. Sánchez-Polo, Adsorbent-adsorbate interactions in the adsorption of organic and inorganic species on ozonized activated carbons: a short review, Adsorption, 17 (2011) 611–620.

[15] A.B. Fadhil, Evaluation of apricot (*Prunus armeniaca* L.) seed kernel as a potential feedstock for the production of liquid biofuels and activated carbons, Energy Convers. Manage., 133 (2017) 307–317.

[16] C. Song, Z. Libo, Z. Hongying, X. Shengzhou, Z. Jinhui, P. Shixing, Crofton weed derived activated carbon by microwave-induced KOH activation and application to wastewater treatment, J. Porous Mater., 23 (2016) 15–17.

[17] S. Suthar, P. Sajwan, K. Kumar, Vermi remediation of heavy metals in wastewater sludge from paper and pulp industry using earthworm *Eisenia fetida*, Ecotoxicol. Environ. Saf., 109 (2014) 177–184.

[18] M. Clements, J. Haarhoff, Practical experiences with granular activated carbon (GAC) at the Rietvlei water treatment plant, Water SA, 30 (2004) 89–95.

[19] U. Bergna, O. Romar, T. Tuomikoski, S. Runtti, H. Kangas, P. Tynjälä, U. Lassi, Waste Biomass Management — A Holistic Approach, L. Singh, V.C. Kalia, Eds., Springer, Berlin, Germany, 2017, pp. 187–213.

[20] M. Ahmedna, M. Marshall, W.E. Rao, Granular activated carbons from agricultural by products: process description and estimated cost of production, Bioresour. Technol., 71 (2014) 113–123.

[21] K. Yang, J. Peng, H. Xia, L. Zhang, C. Srinivasakannan, S. Guo, Textural characteristics of activated carbon by single-step CO_2 activation from coconut shells, J. Taiwan Inst. Chem. Eng., 41 (2012) 367–372.

[22] S. Yorgun, D. Yıldız, Preparation and characterization of activated carbons from Paulownia wood by chemical activation with H_3PO_4, J. Taiwan Inst. Chem. Eng., 53 (2015) 122–131.

[23] M.A. Yahya, Z. Al-Qodah, C.W.Z. Ngah, Agricultural bio-waste materials as potential sustainable precursors used for activated carbon production: a review, Renewable Sustainable Energy Rev., 46 (2015) 218–235.

[24] K.A. Thompson, K.K. Shimabuku, J.P. Kearns, J.P. Knappe, D.R. Summers, R.S. Cook, Environmental comparison of biochar and activated carbon for tertiary wastewater treatment, Environ. Sci. Technol., 50 (2016) 11253–11262.

[25] M.A. Mohammed, A. Shitu, T. Tadda, M. Ngabura, Utilization of various agricultural waste materials in the treatment of industrial wastewater containing heavy metals: a review, Int. Res. J. Environ. Sci., 3 (2014) 67–71.

[26] K. Yang, J. Peng, C. Srinivasakannan, C. Zhang, L. Xia, H. Duan, Preparation of high surface area activated carbon from coconut shells using microwave heating, Bioresour. Technol., 101 (2010) 6163–6169.

Appendix A: characterization of carbon samples

Table A1
Yield of carbon samples

Carbon samples	Weight of raw material (g)	Weight of AC after carbonization (g)	Yield (%)
PPPAC	47.17	27.43	58.15
PPZAC	94.34	53.66	56.88
PCPAC	22.5	3.43	15.24
PCZAC	22.5	3.68	16.36

Table A2
Moisture content of carbon samples

Carbon samples	W_0 (g)	W_1 (g)	Moisture content (%)
PPPAC	1	0.7	30
PPZAC	1	0.77	23
PCPAC	1	0.95	5
PCZAC	1	0.94	6

Table A3
Ash content of carbon samples

Carbon samples	Weight of dry adsorbent (g)	Weight of dry ash (g)	Ash content (%)
PPPAC	1	0.03	3
PPZAC	1	0.16	16
PCPAC	1	0.06	6
PCZAC	1	0.14	14

Table A4
Volatile matter of carbon samples

Carbon samples	Wa (g)	Wb (g)	Volatile matter (%)
PPPAC	0.5	0.23	54
PPZAC	0.5	0.22	56
PCPAC	0.5	0.26	48
PCZAC	0.5	0.2	60

Table A5
Tapped bulk density of carbon samples

Carbon samples	Weight of dry adsorbent (g)	Volume of dry adsorbent (ml)	Bulk density (g/ml)
PPPAC	0.5	1.2	0.42
PPZAC	0.5	1.1	0.45
PCPAC	0.5	1.9	0.26
PCZAC	0.5	1.8	0.28

Appendix B: analysis of treated wastewater

Table B1
Treatment of wastewater using phosphoric acid-activated pineapple peel (PPPAC) at various contact time

Contact time (min)	pH	TDS (mg/L)	BOD (mg/L)	Turbidity (FTU)	TDS reduction (%)	BOD reduction (%)	Turbidity reduction (%)
FEPA limits	(6–9)	<2,000	10–50	0	–	–	–
WWA	4.73	339	78.84	8	–	–	–
30	4.78	183	44.31	2	46.0177	43.8	75
60	4.98	126	33.14	0	62.83186	57.97	100
90	5.24	123	29.08	0	63.71681	63.11	100
120	5.3	119	27.8	0	64.89676	64.74	100
180	5.67	110	25.29	0	67.55162	67.92	100

Table B2
Treatment of wastewater using zinc chloride-activated pineapple peel (PPZAC) at various contact time

Contact time (min)	pH	TDS (mg/L)	BOD (mg/L)	Turbidity (FTU)	TDS reduction (%)	BOD reduction (%)	Turbidity reduction (%)
FEPA limits	(6–9)	<2,000	10–50	0	–	–	–
WWA	4.73	339	78.84	8	–	–	–
30	5.01	124	53.45	4	63.42	32.204	50
60	5.09	108	45.96	2	68.14	41.705	75
90	5.12	102	42.86	0	69.91	45.63	100
120	5.26	101	38.26	0	70.2	51.471	100
180	5.38	98	31.41	0	71.09	60.1598	100

Table B3
Treatment of wastewater using phosphoric acid-activated pineapple crown (PCPAC) at various contact time

Contact time (min)	pH	TDS (mg/L)	BOD (mg/L)	TDS reduction (%)	BOD reduction (%)
FEPA limits	(6–9)	<2,000	10–50	–	–
Raw WW	9.41	42.93	31.36	–	–
30	6.37	31.62	22.47	26.35	28.35
60	6.54	29.58	19.8	31.1	36.86
90	6.71	27.53	12.65	35.87	59.66
120	6.87	25.49	10.12	40.62	67.73
180	7.11	17.3	6.79	59.7	78.35

Table B4
Treatment of wastewater using zinc chloride-activated pineapple crown (PCZAC) at various contact time

Contact time (min)	pH	TDS (mg/L)	BOD (mg/L)	TDS reduction (%)	BOD reduction (%)
FEPA limits	(6–9)	<2,000	10–50	–	–
Raw WW	9.41	42.93	31.36	–	–
30	7.22	23.5	16.54	45.26	47.26
60	7.14	19.19	11.32	55.23	63.9
90	7.01	14.87	7.06	65.36	77.49
120	6.99	10.56	4.22	75.41	86.54
180	6.92	2.93	1.85	93.17	94.1