

PROCESSING AND CHARACTERIZATION OF ACTIVATED CARBON FROM COCONUT SHELL AND PALM KERNEL SHELL WASTE BY H_3PO_4 ACTIVATION

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ABSTRACT

Palm kernel shell and coconut shell are used as a precursor for the production of activated carbon, a way of mitigating the tons of waste produced in Ghana. The raw Palm kernel shell and coconut shell were activated chemically using H_3PO_4 . A maximum activated carbon yield of 26.3 g was obtained for Palm kernel shell and 22.9 g for coconut shell at 400°C, an impregnation ratio of 1.2 and 1-hour carbonization time. Scanning electron microscopy reveals well-developed cavities of the H_3PO_4 activated coconut shell and Palm kernel shell compared to the non-activated carbon. Iodine number of 743.02 mg/g and 682.11 mg/g, a porosity of 0.31 and 0.49 and the electrical conductivity of 2010 $\mu S/cm$ and 778 $\mu S/cm$ was obtained for the AC prepared from the coconut shell and Palm kernel shell respectively. The results of this work show that high-quality activated carbon can be manufactured locally from coconut shell and Palm kernel shell waste, and a scale-up of this production will go a long way to reduce the tons of coconut shell and Palm kernel shell waste generated in the country.

Keywords: Acid Activation, Activated Carbon, Characterization, Coconut shells, Palm Kernel Shells, Waste.

Introduction

Activated carbon (AC) has attracted a lot of attention in industries applications like water treatment (Bentil & Buah, 2016), mining (Buah *et al.*, 2016), energy storage (Mohammed *et al.*, 2018), purification of gases (Hidayu & Muda, 2016), medicine, sewage treatment, and filters (Yusufu *et al.*, 2013). The application of

AC in these industries is possible due to its excellent mechanical property, high porosity, high surface area, the presence of organic/inorganic functional groups and the likes. These properties found in AC is influenced by the precursor and the mode of activation used in its preparation (Abechi *et al.*, 2013; Romeo-Anaya *et al.*, 2012).

TABLE 1
A summary of previous studies carried out on the processing of AC from palm kernel shells (PaKS) and coconut shells (CoS).

Precursor	Chemical agent	Carbonization condition	Optimum Processing time (min)	Optimum Impreg-nation ratio	Yield (%)	Pore volume (cm ³ /g)	Pore diameter (nm)	Porosity (%)	Reference
Coconut Shell	ZnCl ₂	N ₂ /600°C	50	0.4	43	-	-	-	Mozammel <i>et al.</i> 2002
Coconut Shell	H ₃ PO ₄	N ₂ /416°C	19.5	1.725	51	-	578	-	Gratuito <i>et al.</i> 2008
Coconut Shell	KOH	N ₂ /600°C	120	1.51	32.5	1.21	2.05	-	Hu & Srinivasan, 1999
Coconut Shell	ZnCl ₂	N ₂ /550°C	60	1.0	45	0.43	1.817	-	Hidayu & Muda, 2016
Coconut Shell	ZnCl ₂	650°C	60	0.33	-	0.372	-	-	Das <i>et al.</i> 2015
Coconut Shell	NaOH	N ₂ /600°C	120	0.33	77	0.414	2.86	38.32	Islam <i>et al.</i> , 2017
Coconut Shell	H ₃ PO ₄	400°C	60	1.2	48.4	0.62	-	31	This work
Palm Kernel Shell	H ₃ PO ₄	425°C	30	2	50	0.903	3.2	-	Lim <i>et al.</i> , 2010
Palm Kernel Shell	K ₂ CO ₃	800°C	120	1	27.84	0.57	0.52	-	Adinata <i>et al.</i> , 2007
Palm Kernel Shell	ZnCl	N ₂ /550°C	60	1	44	0.70	22.88	-	Hidayu & Muda, 2016
Palm Kernel Shell	KOH	800°C	-	1:1.5	8.93	-	8.931	-	Andas <i>et al.</i> , 2017
Palm Kernel Shell	ZnCl ₂	CO ₂ /500 °C	60	-	30	1.27	-	76.2	Guo, & Aik, 1999
Palm Kernel Shell	H ₃ PO ₄	CO ₂ /500 °C	60	-	28	1.03	-	72.9	Guo, & Aik, 1999
Palm Kernel Shell	KOH	CO ₂ /500 °C	60	-	25	0.77	-	65.7	Guo, & Aik, 1999
Palm Kernel Shell	H ₃ PO ₄	400°C	60	1.2	48	0.94	-	49	This work

A summary of previous studies carried out on the processing of AC from palm kernel shells (PaKS) and coconut shells (CoS) has been outlined in Table 1, indicating the AC yield, the processing condition as well as its properties. From Table 1, it can be observed that the production of AC from PaKS and CoS involves higher temperatures with a corresponding varied percentage of AC yield.

Higher temperatures are a disadvantage in the scale-up of the production of AC and a better and cost-effective method is required to produce AC industrially. The activation process is very key in the production of AC. The shape and the size of pores in the AC is influence by either chemical or physical activation. Chemical activation involves one step process by saturating the precursor with a chemical

reagent followed by roasting or heating under unreactive conditions. Chemical activation generates AC with high yield, high surface area, high and employing lower temperature. Quite a number of the inorganic chemical agent has been used in the activation of AC. The most frequently used are KOH, $ZnCl_2$, H_3PO_4 and NaOH (Williams & Reed, 2004; Singh *et al.*, 2013; Pragya *et al.*, 2013). Generally, the precursors for commercially available AC come from petroleum remains coal, wood, lignite, and peat which are very expensive and likely to run out (Altenor *et al.*, 2009; Ahmedna *et al.*, 2000). As a result, the focus has been shifted to agricultural waste materials which are environmentally friendly, effective and cheaper. Although the carbon yield of AC produced from these agricultural waste materials is lower compared to those obtained from coal or peat, their environmental, sustainability and economic impact can counterbalance the treatment and disposal cost of using peat and coal.

Ghana like any other agricultural country has a lot of agricultural waste that they have difficulty coping with (Miezah *et al.*, 2015). Tons of thousands of agricultural wastes such as coconut shell and palm kernel shell which are by-products of coconut fruit and oil palm respectively are some of the waste that is generated in Ghana yearly. Coconut shells and palm kernel shells, contain a high number of organic constituents (i.e., cellulose, hemicellulose, and lignin) and possess a high-energy content (Tsai *et al.*, 2006; Yahya *et al.*, 2015). A look at the demand in AC in the Gold mining companies and other industrial applications in Ghana that rely on imported AC for their production activities, coupled with the governments of Ghana's intervention

of ensuring the consumption of locally made goods make it vital to pursue the production of AC locally. This implies that the processing of these tons of coconut and palm kernel waste obtained in Ghana into AC could open up a new industry that can employ a lot of people and trim down the cost of AC importation for the mining sector and for other applications. Herein, we report the preparation of AC from PaKS and CoS using H_3PO_4 as the activating agent with the aim of reducing the tons of waste produced in Ghana, to ensure good health and well-being of Ghanaians. The study also seek to improve upon existing technology to obtain a more cost-effective method for the industrial production of AC.

Experimental

Materials, method and sample preparation

The Coconut shell (CoS) were obtained around the Dome market in the Ga-East Municipality and the palm kernel shells (PaKS) around the Madina Market in the La Nkwantanang-Madina Municipality. These sites are the collection point of most of the used coconut shells and palm kernel shells in the municipality. Fig. 1 depicts the map of the sample collection sites mentioned above. The dumping site of the coconut shells and palm kernel shells is shown in Figs. 2a and 2b. The precursors, CoS and PaKS were washed with distilled water to remove dirt and any contamination. The washed CoS and PaKS were then oven dried to remove traces of water. The dried CoS and PaKS were crushed with a Retsch mill (Type-SM1) to reduce their particle size. They were then sieved to the required particle size, using a 350 μm sieve. Figs. 2c and 2d exhibit the milled CoS and PaKS into the required particle size.

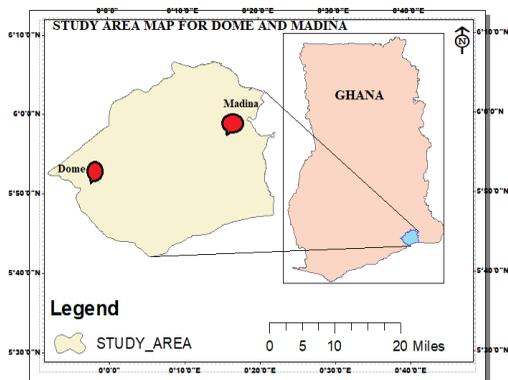


Fig. 1: Study area map for Dome and Madina in Accra, Ghana.

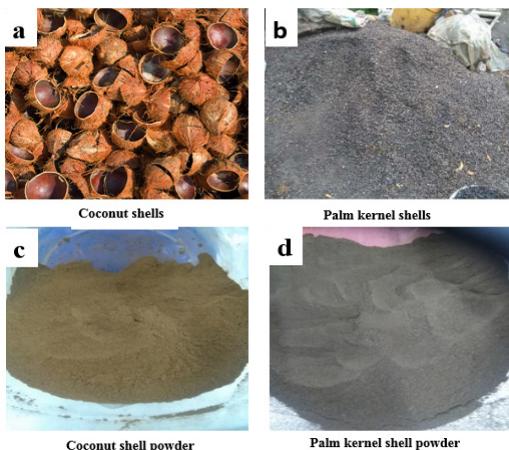


Fig. 2: Palm kernel shells and coconut shells from dumping site in Madina and Dome respectively and their powder.

Activation by H_3PO_4

About 50.0 g each of the precursor was weighed into a beaker and then impregnated by mixing with 1M Phosphoric acid (H_3PO_4 , 99%) to obtain a homogenous mixture and left standing for 24 hours at ambient condition. The impregnating ratios used were 0.6, 0.8, 1.0 and 1.2 (by mass) (Pandharipande *et al.*, 2012). The impregnated samples were dried at 100°C for 12 hours in an oven (Griffin-Grundy). The dried samples were transferred

into canisters and labeled according to sample type, carbonization time, impregnation ratio and temperature. The labeled canisters were introduced by the use of tongs into the Thermolyne furnace (F48028, Thermo Fischer Scientific) maintaining an impregnation ratio of 0.6, carbonization time of 1 hour whilst varying temperature of the Thermolyne furnace (400, 500, 600, 700°C respectively). The optimum temperature ($Topt$) corresponding to the maximum yield was recorded. This procedure was repeated by maintaining the $Topt$ obtained, impregnating ratio whilst varying the carbonisation time (1, 1.5, 2 and 2.5 hours). The optimum carbonisation time ($topt$) was recorded. $Topt$ and $topt$ were maintained whilst impregnating ratios (0.6, 0.8, 1.0 and 1.2) were varied to obtain optimum impregnating ratio ($IRopt$). After each process, the AC samples were allowed to cool down, washed many times with distilled water to remove excess chemicals and then dried at 110°C for 24 hrs. Finally, the samples were collected in sealed bags and stored in a desiccator. For comparison, the raw precursors were treated the same way without H_3PO_4 impregnation.

Characterization of prepared activated carbon

The pH was measured using a pH meter, The moisture content was determined using the "oven drying method" described by Li Lee *et al.*, 2016. A clean empty porcelain capsule was oven dried at 105°C, then cooled in a desiccator and then 1 - 2 g of the sample were weighed. The content was then oven dried at 110°C to constant weight for 3 hours. The percentage moisture content was calculated using the equation below:

$$\text{Moisture content} = \frac{\text{initial weight} - \text{Oven dry weight}}{\text{Oven dry weight}} \times 100\%$$

The percentage of the volatile matter of the AC sample was determined by the standard method (ASTM D5832-98, 2004) and the ash

content (ASTM D2866-11, 2004) method was followed. In a typical procedure, oven-dry samples are placed in a ceramic crucible and the weight of each crucible and the biomass is noted. The crucibles are then placed and in the furnace at a temperature of 900°C for 7 min. After cooling, the volatile content is calculated according to the equation:

$$\text{Volatiles (\%)} = \frac{100 \times \text{mass of the sample after heating}}{\text{mass of oven dry sample}}$$

The bulk density of AC was determined following the method described by Ahmedna *et al.*, 2000 using a measuring cylinder. The iodine number is determined according to the ASTM D4607-94, 2006 method. The iodine number is defined as the milligrams of iodine adsorbed by 1 g of carbon. The experiment consists of treating the sample with 10 mL of 5% HCl. This mixture is boiled for 30 sec and then cooled. About 100 ml of 0.1 N (0.1 molL⁻¹) iodine solution was then added to the mixture and stirred for 30 sec. The resulting solution is filtered and 50 ml of the filtrate is titrated with 0.1 N (0.1 molL⁻¹) sodium thiosulfate, using starch as an indicator. The iodine amount adsorbed per gram of carbon (X/M) was calculated by the equation below

$$\frac{X}{M} = \frac{(N_I \times 126.93 \times V_I - \left(\frac{V_I + V_{HCl}}{V_F}\right) \times (N_{Na_2S_2O_3} \times 126.93) \times V_{Na_2S_2O_3})}{M_c}$$

Where N_I is the iodine solution normality, V_I is the added volume of iodine solution, V_{HCl} is the added volume of 5% HCl, V_F is the filtrate volume used in titration, $N_{Na_2S_2O_3}$ is the sodium thiosulfate solution normality, $V_{Na_2S_2O_3}$ is the consumed volume of sodium thiosulfate solution and M_c is the mass of activated carbon. The AC Sample was heated in a reactor-furnace for two hours at a temperature of 800° C. After heating, the samples were stored in the desiccator for cooling and weighed. The ash content was

calculated using the equation below

$$\text{Ash Content} = \frac{\text{ash weight}}{\text{sample weight}} \times 100\%$$

The porosity of any porous material is defined as the ratio between the total void spaces within the solid porous material and the material bulk volume (Hassan *et al.*, 2015). The porosity in this study was determined by the method used by Evbuomwan *et al.*, 2013. A cylinder and an aluminum plate were each weighed. A sample of activated carbon was placed into the cylinder, reweighed and transferred into the aluminum plate and then oven dried to a constant weight at a temperature of 105 °C for 60 mins. The weights of the sample was recorded after drying. A cleaned, dried density bottle was weighed. A small quantity of sample of activated carbon was taken and ground to powder; sieved using 110 µm mesh size, and gradually put into the density bottle with a little amount of water added and weighed. The volume of the void (V_v) was obtained by first determining the total volume of the cylinder ($V_t = \pi r^2 h$) used for the experiment and also determining the volume of the AC used:

$$V_s = \frac{M_s}{G_s \rho_w}$$

Where r = radius of cylinder, h = height of cylinder, M_s = mass of cylinder, G_s = specific gravity, ρ_w = density of water. The volume of void (V_v) was obtained as: $V_v = V_t - V_s$.

$$\text{Porosity} = \frac{\text{Volume of void}}{\text{Total volume}}$$

Electrical conductivity was measured using Ecoscan conductivity meter (Eutech, Singapore), and values were presented in micro-Siemens, µS/cm as described by (Ahmedna *et al.*, 2000). The surface functional groups, the surface morphology and the decomposition temperature of the carbonized and the activated PaKS and CoS were

determined using Fourier Transform-Inferred spectroscopy (FT-IR, Nicolet iS5, USA), Scanning electron microscopy (SEM, JSM 639OLV) and Thermogravimetric analysis (TGA, N-1000, SCINCO) respectively.

Results and discussion

Effect of Temperature, carbonization time and Impregnation ratio on AC Yield

The effect of temperature on the AC yield was investigated from 400-700°C. From Fig. 3a, it can be seen that PaKS and CoS at 400°C gave the maximum AC yield of 25.7 g and 22.2 g respectively with H_3PO_4 as activating agent. A similar work conducted by (Okoroigwe and Saffron, 2012) in which PaKS was the precursor and H_3PO_4 as the activating agent recorded optimum temperature between 400°C and 500°C. Fig. 3b shows that the maximum yield of AC for PaKS was 25.7 g (H_3PO_4 as activating agent). This corresponded to carbonisation time of 1 hour. Hence, there was a complete decomposition of PaKS within 1 hour of carbonisation. The Maximum mass of AC produced from CoS was 22.3 g (H_3PO_4 as activating agent). This mass of AC produced from CoS occurred within 1.5 hours of carbonisation time. Comparing PaKS and CoS, one can say that economically, production of AC using PaKS as a precursor may be a better option. However, (Jin *et al.*, 2012) reported that at a higher carbonisation time, less amount of AC was produced.

The impregnation ratio was investigated from 0.6-1.2 with the optimum temperature of 400 °C. Generally, Fig. 3c shows that as the impregnation ratio of activating agent to precursor increased, the average mass of AC produced also increased. A similar observation was reported by Mozammel *et al.*, (2002). PaKS and CoS had a maximum AC yield of 27.6 g and 24.2 g respectively (using H_3PO_4 as an activating agent in each case).

These maximum masses (27.6 g and 24.2 g) corresponded to impregnating ratio of 1.2.

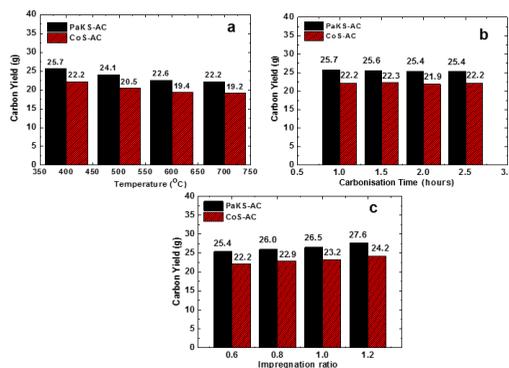


Fig. 3: Carbon yield for Coconut shells and Palm kernel shells as a function of (a) Temperature (b) Carbonization Time (c) Impregnation ratio.

Characterization of activated carbon

TABLE 2

Physicochemical properties of prepared carbon and activated carbon from Coconut shells and Palm kernel shells.

Property	CoS-C	PaKS-C	CoS-AC	PaKS-AC
pH	5.7	5.7	2.6	2.8
Electrical conductivity ($\mu S/cm$)	491	308	2010	778
Pore volume (ml/g)	0.48	0.52	0.62	0.94
Porosity	0.35	0.41	0.31	0.49
Bulk density (g/cm ³)	0.47	0.54	0.41	0.65
Iodine value (mg/g)	194.83	173.01	743.02	682.11
Moisture Content (%)	9.65	8.00	5.41	1.94
Volatile matter (%)	42.49	37.38	35.64	31.86
Ash content (%)	5.95	9.63	7.17	11.88
Carbon content (%)	45.91	45.00	51.78	54.32

The pH values obtained in this study are depicted in Table 2. AC adsorption is affected by pH. At lower pH AC is more effective than at high pH (Evbuomwan *et al.*, 2013). The AC obtained from PaKS and CoS recorded the lowest pH of 2.8 and 2.6 respectively. This indicates that the AC may probably be an L-type and may have acidic oxides predominating its surface as has been reported by Matos *et al.* (2012). However, the

pH values obtained in this study falls within the range of most commercial AC used for adsorption purposes (Erhayem *et al.*, 2016).

High electrical conductivity is a desirable characteristic for commercial AC used as electrode material for supercapacitors (Fan *et al.*, 2011). The electrical conductivity of 2010 $\mu\text{S}/\text{cm}$ was recorded for CoS-AC and 778 $\mu\text{S}/\text{cm}$ for the PaKS-AC. The high electrical conductivity of the AC obtained from both materials is suggestive of its utility in electrochemical devices (Viswanathan *et al.*, 2009). Also, the high electrical conductivity of CoS-AC indicates that its elemental carbon is in graphitic structure and can be useful in the adsorption of gold ions (Soleimani & Kaghazchi, 2008). The electrical conductivities in this study are presented in Table 2.

Pore volume recorded in this study for PaKS-AC was 0.94 ml/g (see Table 2). This value agreed closely to works done by Sethupathi *et al.*, 2015. A decrease in the pore volume is witnessed in the CoS-AC. This observation may be linked to the intrinsic features of PaKS such as the type of lignocellulosic make-up, textural and botanical family (Daud & Ali, 2004).

The porosity of any porous material is defined as the ratio between the total void spaces within the solid porous material and the material bulk volume (Hassan *et al.*, 2015). A porosity of 0.49 (Table 2) was obtained for PaKS-AC followed by a porosity of 0.31 for the CoS-AC. The difference in porosities of the activated carbons produced could be credited to the different raw materials used (Ilomuanya *et al.*, 2017). Pore volume supports the concept that porosity is better in chemically activated carbons (Fierro *et al.*, 2007). Adsorptive capacity is determined by porosity (Verla *et al.*, 2012) and it could be stated that PaKS-AC produced in this study may perform better as an adsorbent.

Bulk density is the mass of carbon that can be contained in a filter of a given solid capacity and the amount of treated liquid that can be retained by the filter cake. The higher the density the better the filterability of activated carbons (Verla *et al.*, 2012). The bulk density of carbons obtained from all the samples studied showed that PaKS-AC carbon has a higher bulk density of 0.65 g/cm^3 which may be due to its high fibre content. A bulk density of 0.41 g/cm^3 was recorded for CoS-AC. This result can be attributed to the material hardness. This value of bulk density in this work was in concordance with similar works obtained by Lee *et al.* and Jambulingam *et al.* (Lee *et al.*, 2016; Jambulingam *et al.*, 2007).

Iodine number is defined as the number of milligrams of iodine absorbed by one gram of AC powder (Gawande & Kaware, 2017). The removal of iodine by the AC is related to their porosity characteristics which determine the degree of accessibility of these molecules. Table 2 shows the iodine values obtained in this study. The highest iodine number recorded in this study is 743.02 mg/g for CoS-AC activated carbon and 682.11 mg/g for PaKS-AC. The higher iodine number of CoS-AC is indicative of a larger adsorption area than those of lower iodine value (Marton *et al.*, 2006). More so the values obtained are relatively close to the works conducted by Jaguaribe *et al.*, (2005) and in the range of values (minimum of 500 mg/g) recommended by the American Water Works Standards as reported by (Verla *et al.*, 2012).

An excellent precursor for the production of adsorbent should be low in moisture content (Ekpete *et al.*, 2017). The lowest moisture content recorded in this study was 1.94% (Table 2) for PaKS-AC which was lower than works conducted by Ulfah *et al.*, (2016) whose moisture content was about 5.42%. A high moisture content, of 5.41%, was obtained for CoS-AC which was concordant

to similar works by Devi *et al.*, (2012). The results obtained suggest that PaKS-AC will make a better adsorbent since it has a lower moisture content. Relative to the moisture content obtained by Ulfah *et al.* (2016) & Devi *et al.* (2012), it could be concluded that the AC produced from the two precursors (PaKS & CoS) are of appreciable quality and thus, will be more effective in water treatment.

A low volatile matter of 31.86% was obtained for PaKS-AC while that of CoS-AC was 35.64% (Table 2). The values were lower compared to works conducted by Sanni *et al.*, (2017) who obtained 57% volatile matter using coconut shells. The difference could be attributed to the varying molarities of the phosphoric acid used. The low percentage of volatile matter in this study may also be a result of the dehydrating effect of the acid which caused the water in the biomass to vaporize and strengthening the covalent bond in the carbon matrix leaving no room for carbon loss (Sanni *et al.*, 2017; Cobb *et al.*, 2012).

The ash content (7.17%) recorded for CoS-AC was in agreement with the study conducted by Sanni *et al.*, (2017), whom, in their analysis obtained an ash content of 7.2% useful inorganic contaminants removal (Sivakumar *et al.*, 2012). Ash content of 11.88 was recorded for PaKS-AC, meaning that PaKS-AC may have higher inorganic constituents thereby increasing the amount of non-ignitable residue as a leftover in the furnace.

Carbon content refers to the percentage char that remains after the mass of the volatiles are eliminated (Ikelle & Ivoms, 2014). Table 2 shows a high carbon content of 54.32 for

PaKS-AC and 51.78 for CoS-AC. From these results, it suggests that both precursors are desirable for AC production.

Fourier transform infrared analysis of activated carbon

FTIR was used to analyze the surface functional groups on the carbon and AC of CoS and PaKS. Fig. 4 depicts the FT-IR spectra of the samples. A look at the FT-IR spectra of AC made from CoS and PaKS shows that most of the functional groups on the surface of the samples were mostly eliminated during carbonization or activation process. These functional groups according to literature are the volatile materials and impurities released at the applied elevated temperature (Yacob, 2008). The FT-IR spectra of AC using the two precursors were successfully produced. The AC(s) retained functional groups such as hydroxyl stretching (O-H) from adsorbed moisture around 3347 cm^{-1} , C=C stretching vibration from aromatic rings around 1550 cm^{-1} and around 1092 cm^{-1} , we observe the R-OH alcohol group (Rugayah *et al.*, 2014). It was found that the H_3PO_4 activation removes most of these functional groups (i.e., comparing the activated and non-activated samples). Furthermore, the peak intensity of these functional groups is more pronounced in PaKS-AC compared to CoS-AC. Thus, the chemical composition of the precursor can greatly affect the surface chemistry of prepared AC. From these results, these kinds of AC will find application in waste management such as the elimination of COD and adsorption of organic pollutants (Evbuomwan *et al.*, 2013, Guo and Lua, 2013).

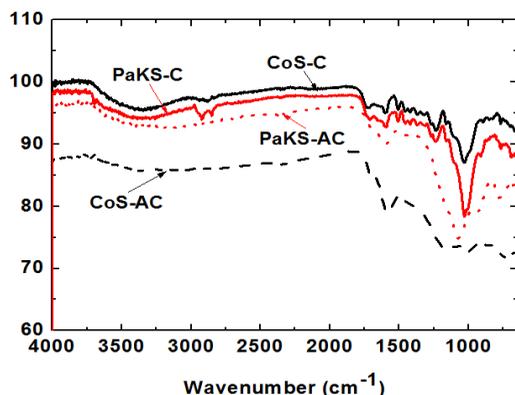


Fig. 4: Fourier Transform-Infrared spectra of carbon and activated carbon synthesized from Coconut shells and Palm kernel shells.

Thermogravimetric analysis of activated carbon

The decomposition temperature of the carbon and AC of CoS and PaKS were investigated using TGA. The TGA micrograph is depicted in Fig. 5. A weight loss of about 66.29% was observed for PaKS and 84.9% for CoS in the temperature range of 25-800 °C. Thus, the PaKS has very high thermal stability compared to CoS. From the TGA profile, the two samples show identical trends. Three stages of weight loss can be observed in all the samples. The first stage is characterized by a weight loss attributed to the escape of moisture, volatile matter and impurities from the sample around 25-112°C. The weight loss in the second stage started decreasing gradually and then sharply from 150-490 for CoS and 150-500 for PaKS and this weight loss may be attributed to the continuous elimination of volatile matter with the release of gases such as carbon dioxide and carbon monoxide (Evbuomwan *et al.*, 2013; Guo *et al.*, 2013). The third stage is characterized by the decomposition of the carbon phase at a temperature above 600 °C (Yacob A., 2008). Comparing the

activated samples and the non-activated ones, it was found that the H_3PO_4 activated samples showed high thermal stability than the non-activated ones for an equal rise in temperature change. From Fig. 5, it can be observed that by 650, only about 10% and 35% of the CoS -AC and PaKS-AC respectively are remaining.

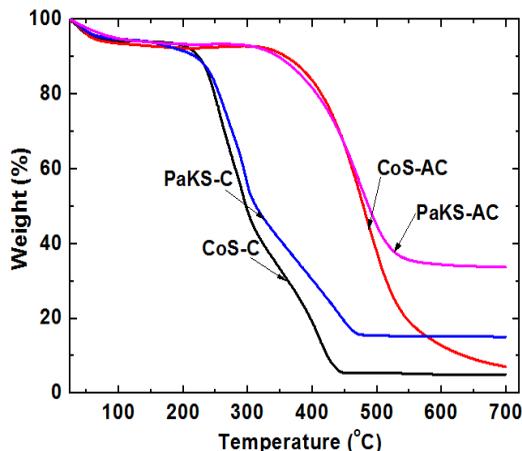


Fig. 5: Thermogravimetric Analysis profile of carbon and activated carbon synthesized from Coconut shells and Palm kernel shells.

Scanning electron microscope of activated carbon

Fig. 6 shows the micrographs of the non-activated CoS and PaKS (a,c) and the activated CoS and PaKS [(b,d)] activation respectively. The non-activated CoS and PaKS carbons, showed a cliff-like mass of flowing lava with insignificant surface pores. On the other hand, well-developed surface cavities can be observed on the H_3PO_4 activated CoS and PaKS carbons. Comparing the size of the cavities, the AC from CoS exhibited larger surface pores compared to the AC from PaKS. This is due to the higher amount of lignin and cellulose found in CoS-AC compared to PaKS-AC. Different agricultural left-overs (precursors) contains a different amount of

lignin and cellulose, which affect the porous form of the prepared AC. It has been found that the decomposition of these complex molecules by heat has a great influence on the surface porosity of the resulting AC. The formation of microstructure and macrostructure is an outcome of higher cellulose and lignin content respectively. The pyrolysis of these agricultural wastes emancipates most of the non-carbon elements like oxygen, nitrogen, and hydrogen in the form of tar and gases (Daud *et al.*, 2000; Ozcimen, & Mericboyu, 2010)

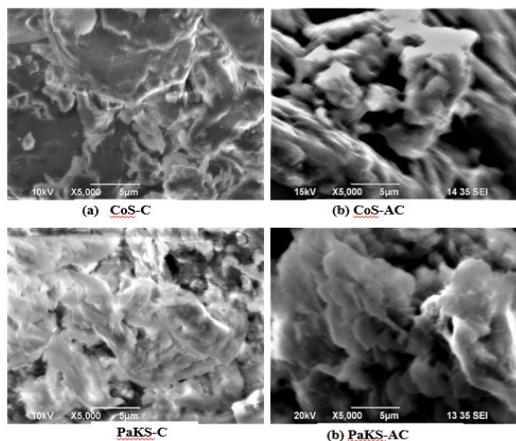


Fig. 6: Scanning electron microscope images of carbon and activated carbon synthesized from Coconut shells and Palm kernel shells.

Conclusion

This study set out to optimize the production of AC from two agricultural byproducts, palm kernel shell, and coconut shell, through chemical activation using H_3PO_4 . Chemical activation of the PaKS and CoS to produce AC was successfully accomplished in a well-controlled laboratory with the application of appropriate instrumentation. PaKS-AC and CoS-AC showed a wider, meso- and macro-porosity. PaKS compared to CoS produced more AC with the same operating parameters and conditions. However, according to the

physicochemical results obtained, PaKS-AC may be a better adsorbent compared to CoS-AC. AC produce locally using agricultural waste can be used as a substitute for imported carbon. A successful large-scale implementation of this study will go a long way to reduce the tons of waste generated in the country, reduce the pressure on the local currency due to importation and create jobs for the citizenry.

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