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Comparative Study: Biochars from *Elaeis Guineensis* Biomasses activated with HCl for Optimum Produced Water Treatment

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ABSTRACT

This investigative study was aimed at comparatively evaluating the characteristics of biochars derived from Elaeis guineensis biomasses and activated with HCl for optimum produced water treatment. The biomasses (palm kernel shells, PKS and empty palm bunch, EPB) were prepared and converted to biochars by pyrolysis, and then activated with 0.2M HCl at a temperature of 450ºC. The ACs (adsorbents) produced were characterised for pH, bulk density, particle size, iodine numbers, ash and moisture contents. The characteristics of the adsorbents indicate that the iodine numbers ranged from 700.14-1181.48mg/g for EPB particle sizes 75-1180 µm; 525.10-918.93mg/g for PKS particle sizes 150-1180 µm; ash content ranged from 6.20-6.80% for EPB and 2.00-2.80% PKS. Moisture content could get as low as 5.4% for EPB and 1.6% for PKS when warmed in an oven at 105ºC for 1 hour. The acid concentration and adsorbent particle sizes were optimized; and based on iodine number, the 300µm particle size for both adsorbents (with pH= 9.8, iodine no.= 962.69, moisture content=5.4% and ash content=6.20% for the EPB, and pH = 7.4, iodine no.=918.93, moisture=6.2% and %ash=2.00 for the PKS) showed good prospects for removing contaminants and was therefore chosen for the treatment. To encourage local content development, it is recommended that activated carbons (Adsorbents) from Elaeis Guineensis biomasses should be mass-produced and used for PW treatment and other purposes. To improve on the adsorption capacity of the PKS any other stronger reagents should be used to activate it since from its bulk density, PKS is a strong material than EPB.

KEYWORDS: Activated Carbon, Adsorption, Agrowastes, *Elaeis Guineesis*. Pyrolysis.

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1. INTRODUCTION

Wastes are generated during agricultural operations (agrowastes) as well as during petroleum exploitation (produced water). Oilfield produced water (PW) is the largest volume of waste generated during petroleum production operations. It is one of the major pollutants to the environmental fresh and sea waters if discharged without proper treatment.

Treatment with activated carbons (adsorbents) is based on the phenomenon known as **adsorption**, in which molecules of a gas or liquid adhere to an external or internal surface of a solid substance. "Adsorption is a surface phenomenon or process that causes accumulation of dissolved substances (such as atoms, molecules, or ions) at the interface of two phases like solid and liquid or solid and gas" (Artioli, 2008; Ujile, 2014; Rizwan *et al.,* 2019). The solid that is used to adsorb gases or dissolved substances is the adsorbent, i.e. the solid on which the adsorption occurs is the absorbent also known as desiccant, whereas the substance that accumulates at the interface (the adsorbed molecules) **is** known as the adsorbate. When adsorption occurs, "molecules tend to concentrate on the surface of an adsorbent as a result of the van der Waals force which exists between the

molecules; the molecules diffusing in the fluid phase are held for a period of time by forces emanating from an adjacent surface. The surface represents a gross discontinuity in the structure of the solid, and atoms at the surface have a residue of molecular forces which are not satisfied by surrounding atoms such as those in the body of the structure. These residuals or van der Waals forces are common to all surfaces and the only reason why certain solids are designated 'adsorbents' is that they can be manufactured in a highly porous form, giving rise to a large internal surface. In comparison the external surface makes only a modest contribution to the total, even when the solid is finely divided." A typical value for the total surface of commercial adsorbents is 400,000 m^2/kg (Richardson *et al.*, 2002)

Activated carbons (ACs) have been prepared from agricultural by-products (also known as agrowastes) such as sawdust, corn cob, coconut husk, waste bamboo, rice husks, nut shells, soya bean oil cake, *Elaeis Guineensis* (oil palm) biomass. *Elaeis guineensis* is a species of palm commonly called oil palm, sometimes also known as African oil palm or macaw-fat (GRIN, 2017). It is among the few tropical tree crops (e.g., bananas and citrus) with high productivity in actual growing conditions, i.e. outside of test plots (Singh *et al.*, 2013). "The palm oil industry in Africa generates, by the processing of palm oil, a large quantity of biomass wastes such as palm kernel shell (PKS), empty palm fruit bunch (EPB), oil palm fibre, etc., whose disposal is a challenging task" (Ikumapayi & Akinlabi, 2018). In fact, for every tonne of palm oil produced from fresh fruit bunches, "a farmer harvests around 6 tons of waste palm fronds, 1 ton of palm trunks, 5 tons of empty fruit bunches, 1 ton of press fibre (from the mesocarp of the fruit), half a ton of palm kernel endocarp, 250 kg of palm kernel press cake, and 100 tons of palm oil mill effluent" (Ruslan *et al.*, 2019).

This is forcing investigation into how these wastes can be turned into wealth by converting them into activated carbons. It is evident from the literature that "various low-cost adsorbents produced from agrowastes have shown good potential for the removal of various aquatic pollutants" (Bhatnagar & Sillanpaa, 2010; Ademiluyi & David-West, 2012; Ademiluyi, 2016) "These waste materials have proved to be promising raw materials for the production of AC with a high adsorption capacity, considerable mechanical strength, and low ash content." Thus, conversion of waste materials into ACs would add considerable economic value, help reduce the cost of waste disposal and most importantly provide a potentially inexpensive alternative to the existing commercial ACs (Adegoke & Bello, 2015).

There are two basic steps for the preparation and production of AC: (1) Carbonization/pyrolysis of the raw precursor material under anaerobic conditions below 1000 °C, and (2) Activation of the carbonized product (biochar), which may be either physical or chemical. Mo *et al.* (2018) noted particularly that "most agrowastes are not currently used in their raw, original state, but modified in a variety of ways to reinforce the porosity and adsorption surface area of the material – Nanostructuring, carbonization, activation and grafting are some common modification technologies of agricultural waste adsorbents." They also summarized "the characteristics, preparation and application of adsorbents from various industrial wastes, including natural materials and biosorbents."

Production. The carbonization process includes drying and then heating to separate by-products, from the raw material, as well as to drive off any gases generated. The carbonization process is completed by heating the material at 400–600°C in an oxygen-deficient condition that cannot support combustion (DG, 2001).

"Biochar preparation methods are mainly pyrolysis, hydrothermal carbonization, gasification, and other methods. Pyrolysis is a thermo-chemical decomposition reaction under high temperature and anoxic conditions. Based on

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pyrolysis time, temperature, and heating rate, pyrolysis can be divided into slow pyrolysis, rapid pyrolysis, and 'flash' pyrolysis (heating rate up to 1000°C/s).

Slow pyrolysis is "characterized by lengthy solid and gas residence times, low temperatures and slow biomass heating rates. In this mode, the heating temperatures ranges from 0.1 to 2 °C per second and the prevailing temperatures are nearly 500°C. The residence time of gas may be over five seconds and that of biomass may range from minutes to days. During slow pyrolysis, chars are released as main products as the biomass is slowly devolatilized. (Ajayi *et al.*, 2020; Cheah *et al.*, 2016; Daful & Chandraratne, 2018; Zhang *et al.*, 2019; Rizwan & Shafiul, 2019).

Characteristics. The physico-chemical properties of biochar vary with the types of raw material, the particle size of the feedstock, the means of pyrolysis, the temperature (including the rate of temperature rise), the time of pyrolysis, and the modification conditions. Although the structure of biochar is affected by many factors, in general, biochar has abundant surface functional groups (hydroxyl, carboxyl, carbonyl, and methyl), the developed pore structure, the high specific surface area, and the stable molecular structure with good adsorption performance, which is favourable to adsorb pollutants" (Tan *et al.*, 2015; Zhao *et al.*, 2015).

Activation. The product of pyrolysis will not be porous unless it is given additional treatment or activation to generate a system of fine pores. The yield and the characteristics of the prepared activated carbon, however, depend on the process of preparation used. Adsorption capacity is enhanced by activating the surfaces (Sincero & Sincero, 2015; Richardson *et al.*, 2002). **"**The carbonized product is 'activated' by exposing it to an activating agent, such as steam, acid, etc, at high temperature. The size of the pores developed during activation is a function of the time that they are exposed to the activating agent. Longer exposure times result in larger pore sizes. The most popular aqueous phase carbons are bituminous based because of their hardness, abrasion resistance, pore size distribution, and low cost, but their effectiveness needs to be tested in each application to determine the optimal product" (DG, 2001).

Activation of the carbonized product (char) may be either physical or chemical. Physical activation is "a process in which the precursor is developed into AC using gases and is generally carried out in a two-step process. It involves contacting the char with an oxidizing gas, such as carbon dioxide, steam, air or their mixtures, in the temperature range between 600 and 900 °C, which results in the removal of the more disorganized carbon and the formation of a well-developed micropore structure" (Sincero & Sincero, 2015). "In the Chemical activation process, the two steps are carried out simultaneously, with the precursor being mixed with chemical activation agents (such as $ZnCl_2$, KOH, NaOH, K_2CO_3, etc) at very low temperatures. This agent will increase the surface area and reduce the ash content of final carbonized products: the chemical incorporated to the interior of the precursor particles reacts with the products resulting from the thermal decomposition of the precursor, reducing the evolution of volatile matter and inhibiting the shrinking of the particles; in this way, the conversion of the precursor to carbon is high, and once the chemical is eliminated after the heat treatment, a large amount of porosity is formed" (Rodriguez-Reinoso & Molina-Sabio, 1992).

"After activation, the char may then be processed into two finished products: a powered form called PAC (powdered activated carbon) and a granular form called GAC (granular activated carbon). PAC is normally less than 200 mesh, and GAC greater than 0.1 mm in diameter" (Sincero & Sincero, 2015).

Characterization. The characterization of activated carbon involves determining such properties as particle size distribution, surface area, apparent and bulk densities, "pore volume,

percentage burnt off, moisture content, ash content, methylene blue adsorption, and iodine number" (DG, 2001; Ademiluyi *et al.,* 2007; Ademiluyi & Nze, 2016a;). Ademiluyi & Nze (2016b) characterized "activated carbon from Bamboo used for the batch adsorption of Ni, Cu, Zn, Pb, Cd, and Cr ions in solution from refinery wastewater compared with reference activated carbon."

Despite the fact that many activated carbons have been produced and used by many authors in the treatment of wastewaters, there is the need to still produced and characterise activated carbons from *Elaeis guineensis* biomasses which is abundant in many States in Nigeria, especially the South-South, with no information yet on the characterisation of the biomasses or availability of information to ascertain the effectiveness of the two biomasses for such treatment. This experimental investigation was limited to evaluating the characteristics of biochars produced from *Elaeis guineensis* biomasses and activated with hydrochloric acid (HCl) for optimum produced water treatment. Thi*s* is with the view to determining the qualities of these activated carbons (ACs) which would be employed in treating oilfield produced water and other wastewaters to reduce the concentration of contaminants in them to enable reuse or safe disposal. The aim of this study, therefore, is to perform a comparative study on production, activation and characterisation of biochars from *Elaeis guineensis* biomasses activated with HCl for optimum produced water treatment.

2. MATERIALS AND METHODS
2.1 Materials
The basic materials used in this work were: agrowastes [*Elaeis Guineensis* Biomasses – EPB and PKS] and reagents [such as thiosulfate solution, Potassium Iodide (KI), and starch]. The agrowaste samples used for the production of the ACs were obtained at no cost from local Palm oil Mills in and around Port Harcourt, Rivers State, Nigeria.

2.2 Methods
2.2.1 Production of Biochar from Agrowastes (EPB and PKS) by Pyrolysis
Carbonization of the agrowastes (2 kilograms of washed, cut, and dried oil palm biomass) was carried out in a pyrolysis reactor (Pyrolyser). The experimental set-up of the pyrolysis process is shown in Plate 1. The agrowaste materials were carbonized at about 300-350^{0}C for two or more hours after which the biochars were allowed to cool to room temperature. The charred materials were crushed using mortar and pistol.

Plate 1: The Experimental Set-up of the Pyrolysis process

2.2.2 Activation of Biochar
The procedure for the activation of the biochars started with the dilution of the concentrated acid: the reagent (hydrochloric acid, HCl, of particular concentration) was prepared from the concentrated acid. The volume of concentrated acid to be added to 1 litre (1000 ml) of distilled water was calculated. For the purpose of characterization and to determine the optimum concentration of HCl to be used to activate the biochar, 100g of each carbonised sample was carefully weighed and put in beaker containing about 300 ml of dilute HCl acid of given concentration. The five concentrations of the dilute acid considered were 0.05, 0.1, 0.2, 0.3 and 0.4M. The content of the beaker was thoroughly mixed until it formed a paste. The paste was then

transferred to a crucible, which was placed in an electric furnace (Carbolite AAF1100) and heated to 450°C for 1 hours. The activated sample was then allowed to cool to room temperature before washing with distilled water to a pH of 7.0 – 9.5 and dried in the electrical oven (Memmert UN75) at 105°C for 1 hour. The pH tester used was the Erma Instruments pH tester calibrated using 7.0 buffer solution prepared at 25°C.

2.2.3 Characteristics of the Activated Carbon:

Characterization of the activated carbons involved the determination of properties such as particle size, bulk density, moisture content, ash content, benzene adsorption, methylene blue and iodine number, and pore volume. The XRF and SEM was used to determine the chemical composition (metallic and organic contents) and surface morphology of the absorbents.

Particle Size Distribution: Sieves were used to determine the following particle sizes. The sieves were arranged with the sieve with the highest mesh size (2360µm) on the top and the 75-µm mesh size at the bottom. Sieving was done by pouring the grind AC sample on to the topmost sieve, then with gentle shaking, the various particle sizes: 75, 150, 300, 600 1180, 2360 µm were obtained.

Bulk Density: An empty test tube was weighed using the portable digital electronic weighing balance (Type: Professional Digital Table Topscale) and the tare mass in gram (g) recorded. The tube was then filled to the brim with the sample, tapped 10 times gently on the table and weighed. The mass of the tube plus the sample in gram was also recorded. The calculation of the bulk density then followed.

Ash content: ASTM (D2866 Standard Method test): The mass of an empty crucible was determined with the aid of the portable electronic weighing balance and recorded as W_1. Five (5) grams of each sample of ACs was measured into the crucibles, and the weight of the crucibles plus the samples were recorded as W_2. The crucibles plus the samples were then put into the electric furnace (Carbolite AAF1100), which was set at 600°C for 6 hours. After 6 hours, the crucible plus dried or ashed samples were left in the furnace to cool to room temperature before they were removed from the furnace, weighed and the masses recorded as W_3. Calculation of the ash content was done using the Equation 1:

$$\% \text{ Ash} = \frac{W_3 - W_1}{W_2 - W_1} \times 100 \qquad (1)$$

Adsorption Capacity - Methylene Blue Test: This test was done using the AAS (atomic absorption spectrophotometer) to analyse the filtrate from the samples to determine the adsorption capacity of the adsorbents. One (1) gram of methylene blue dye was measured/weighed into 1000 ml of distilled water and stir to mix, then 30 millilitres of it was measured out into a new bottle, and 0.3 grams of the activated carbon added to it and stirred to mix. The electric shaker (Stuart Orbital Shaker/ SSL1) was used at an appropriate rotation speed of 200 rotation per minute (200rpm) for 30 minutes to shake and mix samples properly, but the mixed samples were allowed for 2 hours before decanting. Using filter paper, filtration each of the mixture of methylene blue was done. The AAS ("atomic absorption spectrophotometer") was then used to analyse the filtrate, measure the absorbance using a wavelength of 600 metres, "to determine the adsorption capacity of the adsorbents." The absorbance (result) for each sample was recorded and then determination of the methylene blue (MB) absorbance [as the difference between the blank and Absorbance (Abs) values; i.e. MB = Blank – Abs], followed.

Iodine Number Determination: The materials for the determination of the iodine number were thiosulfate solution, Potassium Iodide (KI), and starch. The thiosulfate solution was prepared by dissolving 17.6 grams of the thiosulfate crystals into 1 litre of distilled water and leaving it for 24 hours. A solution of Potassium Iodide (KI) was

also

prepared by dissolving 24g of KI in 1 litre of distilled water. Both solutions were kept for the same 24 hours. The indicator, the starch solution, was then prepared by dissolving 0.3 gram of it in 30ml of distilled water, with 70ml boiled distilled water added to it and stirred until properly mixed. At this point, 10ml of the filtrate was Measured in to a beaker and 2-3 drops of the starch solution added to the filtrate as an indicator. Titration of the thiosulfate solution against filtrate of the KI solution was done until the filtrate turned colourless. the initial and the final volumes were recorded. The titre value, S was obtained by subtracting the initial value from the final value, and recorded. The procedure was repeated for the blank (which is the control) without the adsorbent.

Moisture Content: The moisture cup was used for the moisture content determination. The procedure was simply to measure the mass of the empty moisture cup and record it as M_1. Then, measure 5 grams of each sample of AC into the moisture cup, weigh the cup plus the sample and record as M_2. Put the moisture cup plus the sample into the electric oven (Memmert UN75) and heat it at 105^oC for 3 hours until the moisture content is minimal; the moisture cup plus the sample was removed from the oven and weighed every 1 hour until the mass was constant. The moisture cups containing the dry samples were removed from the oven, weighed and the masses recorded as M_3. Calculation of the moisture content (MC) was performed using the Equation 2.

$$\% \, MC = \frac{M3 - M1}{M2 - M1} \times 100 \qquad (2)$$

3. RESULTS AND DISCUSSION
3.1 Production of the Adsorbents from *Elaeis Guineensis* Biomass
The experimental results of the pyrolysis process performed on the *Elaeis Guineensis* agrowaste materials, namely PKS and EPB at the Petroleum Laboratory, Rivers State University (RSU) are presented in Figures 1 and 2.
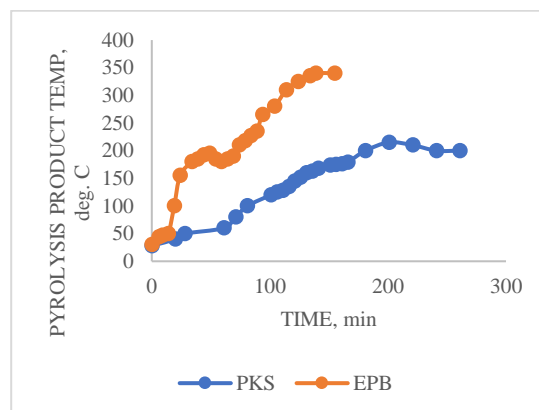

Fig. 1: A Plot of Pyrolysis Product Temperature versus Time for both Biomasses of *Elaies Guineensis* (PKS and EPB).

From Figure 1, the pyrolysis time is a function of several factors such as the pyrolysis temperature, the strength of the materials, heat intensity, and draught (breeze/wind speed). The temperature depends on the intensity of the heat energy used. The higher the temperature, the shorter the time taken to carbonize the biomaterial samples. Heat was applied to the pyrolysis reactor until the volume of bioliquid recovered was constant as can be seen in Figure 2. The empty palm bunch (EPB) carbonized at a shorter time than the palm kernel shell (PKS) because of their relative strengths; the EPB is a lighter material than the PKS.
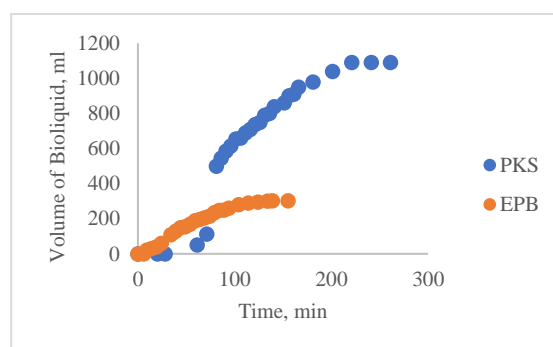

Fig. 2: A Plot of the Volume of Bioliquid recovered from both Biomasses of *Elaies Guineensis* (PKS and EPB) at various Times during Pyrolysis of Samples.

The total volume of the bio-liquids recovered from the PKS and EPB biomass depending on the quantity of each that entered the pyrolysis reactor, comprising mainly of oil and water, were

1104.00ml
and 306.00ml, respectively. The distillation process will confirm the actual proportion of liquids recovered (volume of oil and water) during the pyrolysis process. The components that could not be condensed were basically vapor (gases) produced when the agrowastes were subjected to heat in the absence of air. These bioliquids can be refined into biofuels, but this work did not consider this aspect.

Particle Size Distribution: Sieves (in Plate A.1) were used to determine the following particle sizes: 75. 150, 300, 600 microns (µm), 1.18 mm (1180 µm), 2.36 mm (2360µm), and remnant particle sizes (> 2.36mm, granular AC). The total masses of the biomass before the pyrolysis were 3.6 kg and 2 kg of PKS and EPB, respectively. They were pyrolyzed at a maximum temperature of 230 and 350°C, respectively. The total masses of biochar recovered after the process were 1.747 kg PKS and 0.776kg EPB, which translated to 485.27g biochar/kg of PKS and 388g of EPB biochar/kg of EPB pyrolyzed.

Bulk Density of the Activated Carbons used for Treatment of PW
The results of the weighing and computation of the bulk density of the various sample (sieved) sizes were also plotted in Figure 3. The average bulk densities were determined as 1.1894 g/ cm^3 for PKS and 0.4542 g/ cm^3 for EPB. From the work of Ademiluyi and Nze (2016a), activated carbon from waste Nigerian bamboo had an average bulk density of 0.458 g/cm^3 (reference range: 0.2-0.6 g/cm^3). Therefore, EPB having a bulk density of 0.454 g/cc, is a lighter material than the AC from the PKS and waste bamboo. "Higher apparent or actual density provides greater volume activity and normally indicates better-quality activated carbon" (DG, 2001).
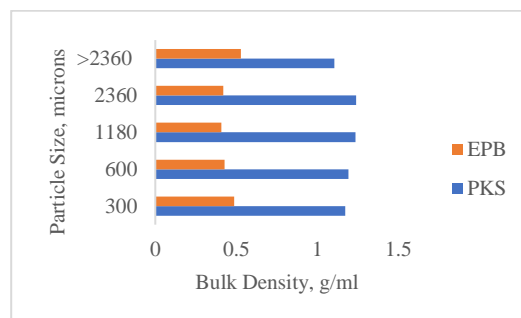

Fig. 3: Bulk Density of AC samples according to their Particle Sizes.

3.2 **Results of the Activation of Samples**
3.2.1 **Optimizing Acid Concentration**
The results (of the pH of activated samples for the 600-micron particle size after washing with distilled water) are plotted in Figure 4. The biochars were activated with different concentrations of dilute HCl, cooled to room temperature, and washed with distilled water to a pH range of 6.5 – 10.0. These activated and washed samples were dried in an oven at 105°C for 1 hour. For economic reasons (that is, because of cost), one particle size (600 µm) was chosen and used – the intent was to find an optimum concentration of the HCl acid with which to activate all the particle sizes.

The results show that the EPB had higher pH than PKS activated samples (Figure 4). The observed trend of the pH versus acid concentration in Figure 4 is interesting. There was an initial gradual increase in pH with increasing acid concentration from 0.05M, stabilized from 2.0 to 3.0M, then, dropped from 3.0M to 4.0M. This is in agreement with the work of Rabia *et al.* (2019). What could be responsible for the fall? The gradual increase in pH with increasing acid concentration is correct but acid concentration increasing beyond 3.0M may have caused starch to hydrolyse to glucose, thereby causing the drop in pH. From the work of Rabia *et al.* (2019), the removal of nutrients/pollutants from a waste stream increases with increasing pH.

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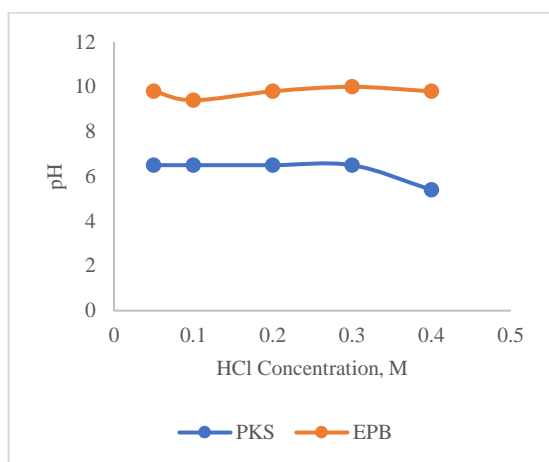**Available online at** https://conference.rsujnet.org/

Fig. 4: pH of the washed 600-micron Biochars Activated at Various Acid Concentrations.

Flowing from the above argument, the optimum acid concentration is 0.2M as can be observed from Figure 4; the 0.2M concentration of the HCl acid is optimum and was thus used for the activation of all the samples for the purpose of the treatment. The final activated products were used for the characterization.

3.3 Characteristics of the Biochars produced from *Elaeis Guineensis* Biomass

Iodine Number. Form the results of characterization of the biochars of oil palm biomasses (EPB and PKS), activated with different HCl concentrations, the plots of the iodine numbers are displayed in Figures 5. The acid concentration was optimized. The iodine numbers of 918.93 and 1181.5 g of Iodine/kg of carbon, respectively, of PKS and EPB biochar samples, corresponding to an acid concentration of 0.2M HCl, are within the acceptable range of 500-1200g of Iodine/kg of carbon (Mianowski *et al.*, 2007; Ademiluyi and Nze, 2016a). At 0.2M concentration HCl acid, iodine numbers are highest for both adsorbents. Therefore, the 0.2M HCl concentration (having the highest iodine numbers) was chosen as the optimum concentration to be used to activate all the sample sizes for the treatment of the produced water effluent for best adsorption. This is also in agreement with what was obtained in Figure 4.
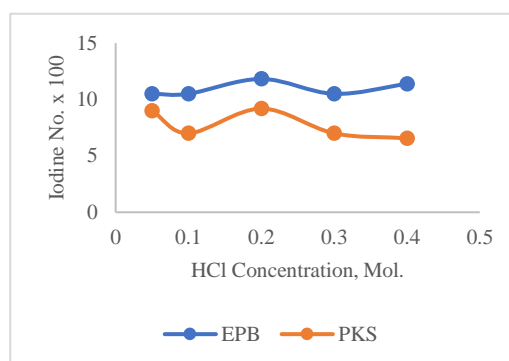

Fig. 5: Iodine Number of Biochars activated with different HCl Acid Concentrations for the 600μm Particle Size.

Ash content: The ash contents for the two adsorbents (PKS and EPB) at 0.2M acid concentration for the 600 μm size were 2.6 and 7.8%, respectively. This one particle size of the adsorbents was chosen just for the purpose of optimising the concentration of the acid, so that that particular concentration would be used to activate the adsorbents for the treatment. It is important to remark that because ashing was done at a high temperature of 800ºC, all the crucibles used cracked. To avoid destroying the crucibles, subsequent determination of the ash content was performed at a lower temperature of 600ºC but for a longer time.

Methylene Blue: Results of Methylene Blue Test for 600 μm size for the different concentrations show that the EPB carbon performed better than the PKS. This means that the EPB has better meso pore structure that can adsorb medium sized molecules than PKS. Some ACs have a meso pore "(2 to 5 nm) structure, which adsorbs medium-size molecules, such as the methylene blue dye" (DG, 2001)

3.4 Characteristics of Biochar Activated with 0.2M HCl

The characteristics of the particle sizes considered was compiled from experimental results for moisture content, ash content and the iodine numbers, respectively determined after the activation of all the AC samples with 0.2M HCl. Figures 6-8 showing the moisture content, ash

content and the iodine numbers, respectively, of the biochars activated with 0.2M HCl for the stated particle sizes.

From Figure 6, which shows the moisture content of Biochars of different sizes activated with 0.2M HCl, it can be observed that the EPB carbon attracts more moisture from the atmosphere than PKS.
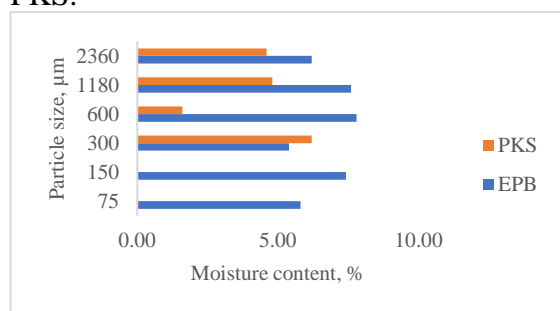

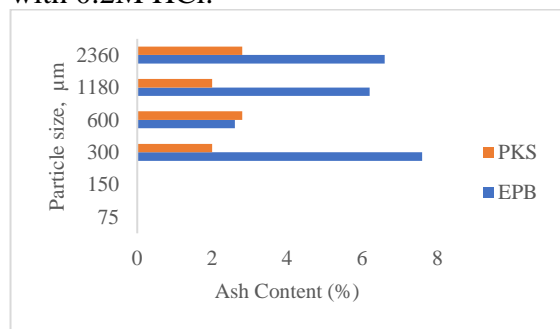Fig. 6: Moisture Content of Biochars activated with 0.2M HCl.

Fig. 7: Ash content of Biochars activated with 0.2M HCl.
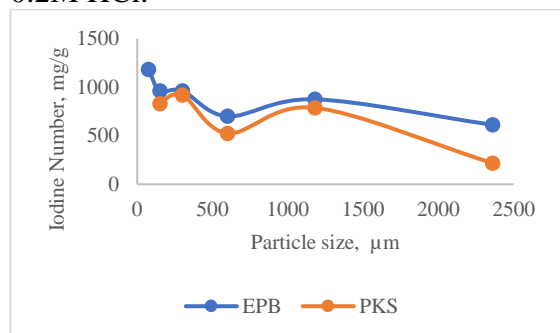

Fig. 8: Iodine Number of Biochars of different Particle Sizes activated with 0.2M HCl.

Activated carbons are naturally hygroscopic, meaning, they attract a lot of moisture from the atmosphere. Figure 7 is a plot of the ash content versus particle size. As can be observed from the graph, the EPB has more ash than the PKS activated carbon. The ash "reduces the overall activity and efficiency of reactivation of activated carbon: the amount of which depends completely on the precursor (raw material) used to produce the activated carbon." It should be noted that a lower temperature (600°C) was used for ashing because a higher temperature (800°C) used at first destroyed the crucibles.

From the results obtained and presented in Figure 8, iodine numbers are observed to decrease steadily with increasing particle size for the two activated carbons; The EPB has iodine numbers riding above those of the PKS. The lower particle sizes having higher iodine numbers; particle sizes: 75, 150, 300, 600 to 1180**µm** (1.18mm) performed well, having higher iodine numbers than the 2360 **µm** (2.36mm) size. High iodine number means larger surface area and greater adsorption capacity for the particle sizes in this range.

The optimum particle size needs to be found since all the particle sizes cannot be used for the treatment for economic reasons. Looking at Figure 8, it was clearly seen that the 300-micron particle size (with 962.69 mg/g and 918.93mg/g for EPB and PKS, respectively) has considerably high iodine numbers for the both ACs (adsorbents), and was therefore chosen as the optimum particle size to be used for the treatment.

For the EPB, the 75 and 150-micron sizes have higher iodine numbers than the 300-micron size. However, the latter size was chosen for the treatment. From the literature, "two particle size criteria are the effective size and the uniformity coefficient; generally, the rate of adsorption will increase as the particle size decreases, as the process step of diffusion to the carbon surface should be enhanced by the smaller particles" (DG, 2001). "Another critical aspect of rate of adsorption is the pore size distribution, and the development of 'transport pores' within the particle that allow effective migration of

contaminants to the point of adsorption – particle size, however, may not be that important in all cases, as the porous nature of the carbon particles results in large surface areas in all sizes of carbon particles, but headloss through a carbon bed increases as the carbon particle size decreases and as the uniformity coefficient increases" (DG, 2001).

Empty palm bunch, EPB has a higher ash content than PKS. It should be noted that these adsorbents are naturally **hygroscopic**, meaning, they attract a lot of moisture from the atmosphere. Therefore, the particle size chosen for the treatment of the PW has to be dried in the oven at 105ºC for, at least, 1 hour before use to reduce the moisture content.

4 CONCLUSION

Activated carbons have been produced by pyrolysis from *Elaeis Guineensis* biomass (PKS & EPB), which have excellent qualities and can be used for produced water treatment for either disposal or reuse.

The characteristics of the adsorbents (ACs) produced indicate that the iodine numbers ranged from 700.14-1181.48 mg/g for EPB particle sizes 75-1180 µm; 525.10-918.93 for PKS particle sizes 150-1180 µm); ash content ranged from 2.60-6.20% for EPB and 2.00-2.80% PKS. Moisture content could get as low as 5.4% for EPB and 1.6% for PKS when warmed in an oven at 105ºC for 1 hour. The acid concentration and adsorbent particle sizes, were optimized; and based "on iodine number and methylene blue" adsorption capacity, the 300µm particle size for both adsorbents showed good prospects for removing contaminants, and can therefore be chosen for the treatment of produced water. In this research work, hydrochloric (HCl) acid was used for the activation of the biochars in the production of the ACs. It is, however, recommended that the PKS, in further research, should be activated with a stronger acid or reagents to improve its adsorptive capacity. To encourage local content development, ACs from *E. Guineensis* Biomasses should mass-produced & used for PW treatment and other purposes such water purification, carbon capture and sequestration, etc.

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