Nigerian Research Journal of Engineering and Environmental Sciences 6(2) 2021 pp. 741-752
p ISSN: 2635-3342; e ISSN: 2635-3350

Nigerian Research Journal of Engineering and Environmental Sciences
Journal homepage: www.rjees.com

Original Research Article

Treatment of Rubber Latex Processing Wastewater using Activated Carbon Derived from Palm Kernel Shell

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http://doi.org/10.5281/zenodo.5805379

ARTICLE INFORMATION

Article history:
Received 12 Aug, 2021
Revised 26 Sep, 2021
Accepted 03 Oct, 2021
Available online 30 Dec, 2021

Keywords:
Activated carbon
Adsorption
Palm kernel shell
Rubber latex
Wastewater

ABSTRACT

The rate at which untreated wastewater from rubber latex industry are discharged into the water bodies and its attendant consequences on humans and the environment is worrisome. Hence, this research sought to evaluate the efficacy of palm kernel shell (PKS) activated carbon as a low-cost adsorbent in the treatment of rubber latex wastewater. The PKS was carbonized at 500 °C for 2 hours and activated with HCl at 105 °C for 4 hours in a furnace. The char formed was crushed and sieved to produce the granular PKS activated carbon (GPKSAC). The char was also ground to produce powdered PKS activated carbon (PPKSAC). The fixed bed adsorption technique was used to treat the rubber latex processing wastewater at predetermined flow rates. The PKS activated carbon exhibited high performance for the adsorption of organic matter when expressed in terms of chemical oxygen demand (COD). Scanning electron microscopy and Fourier transform infrared spectroscopy (FTIR) analysis revealed excellent morphology and functional groups present in the PKS activated carbon respectively. Freundlich and Langmuir isotherms were used to unravel the adsorptive behavior of contaminants unto the GPKSAC and PPKSAC. The PKS proved effective in the removal of considerable amount of organic and inorganic contaminants in rubber latex processing wastewater.

1. INTRODUCTION

As population grows, industrial activities also increase. Water which is an essential commodity is also being increasingly utilized in the various production processes of these industries. However, industries have long been implicated in the discharge of toxic materials into the environment. Industrial pollution has been

identified as a priority environmental problem, which must be stopped without delay before disastrous health and irreversible environmental problem occurs (Adewumi *et al.,* 2016). The effects of untreated or poorly treated industrial and municipal wastewater on agricultural soils and water can be detrimental to public health, the environment, and the economy at large (Adewumi *et al.,* 2010).

Wastewater management is in very deplorable conditions in many cities of developing countries including Nigeria because of weak institutional capacities and lack of financial resources and institutional framework to tackle the menace (Adewumi and Ajibade, 2019). The current problems in wastewater treatment stem primarily from the increasing pollution of waters by organic compounds that are difficult to decompose biologically (Ajibade *et al.,* 2021a). Conventional methods of industrial wastewater treatments have limitations such as high cost of operation and secondary pollution effects (Pam *et al.,* 2018). Hence, the search for efficient and cost-effective solution. Adsorption by activated carbon is crucial because the organic substances in wastewater that are difficult to decompose by ordinary mechanical processes can be selectively removed by activated carbon (Ademiluyi *et al.*, 2009).

Several researchers have examined the viability of substituting low-cost adsorbents for the preparation of activated carbon in order to eliminate pollutants from industrial wastewaters using a variety of agricultural products (De Gisi *et al*., 2016; Pam *et al.,* 2018). Abbaszadeh *et al.* (2016) reported the performance of activated carbon produced from papaya peel as a bioderived adsorbent in the removal of Pb (II) from metal-contaminated. Masound *et al.* (2016) researched on the use of activated carbon produced from rice husk for the removal of Fe (III) and Mn (II) ions from El-Umum drain water, Alexandria coast, Egypt. Omotade *et al.* (2019) evaluated the performance of a charcoal-based constructed wetland in treating aquaculture wastewater and concluded that they have great potential for the treatment of aquaculture wastewater and prevention of environmental degradation. Also, Ijaola and Omotosho (2020) utilized and compared the efficiency of activated carbon produced from cassava peels and waste bamboo for the adsorption of heavy metals in agricultural wastewater with both biomasses showing effective adsorption.

Although, the use of palm kernel shell (PKS) as adsorbent is well documented but its application in complete treatment of rubber latex wastewater has not been investigated. Jumasiah *et al.* (2005) investigated the sorption kinetics and equilibrium of basic dye onto PKS activated carbon. The study concluded that PKS could be used as a low-cost alternative in wastewater treatment for dye removal. Pam *et al.* (2018) successfully applied PKS activated carbon modified with ethylenediaminetetraacetic for the removal of Pb (II) from aqueous solution while Anyika *et al.* (2017) converted activated carbon produced from PKS into magnetic activated carbon and successfully used it for the removal of arsenic (III) from wastewater.

Oil palm cultivation is predominant in Ondo State, Nigeria especially in the coastal area of the State with heaps of PKS as leftover from the oil extraction processes of the fresh oil palm fruit bunches (Rugayah *et al*., 2014). Currently, rubber is harvested mainly in the form of the latex from the rubber tree. The plant product is a complex mixture of organic substances, including various gum resins, fats, or waxes and, in some instances, poisonous compounds, suspended in a watery medium in which salts, sugars, tannins, alkaloids, enzymes, and other substances are dissolved (Anitha *et al*., 2007).

The rate at which wastewater from rubber latex industry in Araromi Obu, Ondo State are discharged into the water bodies untreated calls for concern. The use of sustainable and low-cost agricultural waste product like the PKS for the production of activated charcoal for the wastewater treatment will greatly improve the quality of industrial effluent and eliminate its negative impacts on human and the environment. Hence, this research evaluates the efficacy of PKS activated carbon as an adsorbent in the treatment of rubber latex wastewater.

2. MATERIALS AND METHODS

2.1. Study Area

This study was carried out in Rubber Estate Plantation, Araromi Obu in Odigbo Local Government Area of Ondo State (Figure 1). The plantation covers about 50 km^2 expanse of land and also houses a mini processing. The area in general has a vast oil palm plantation cultivated by individual farmers.

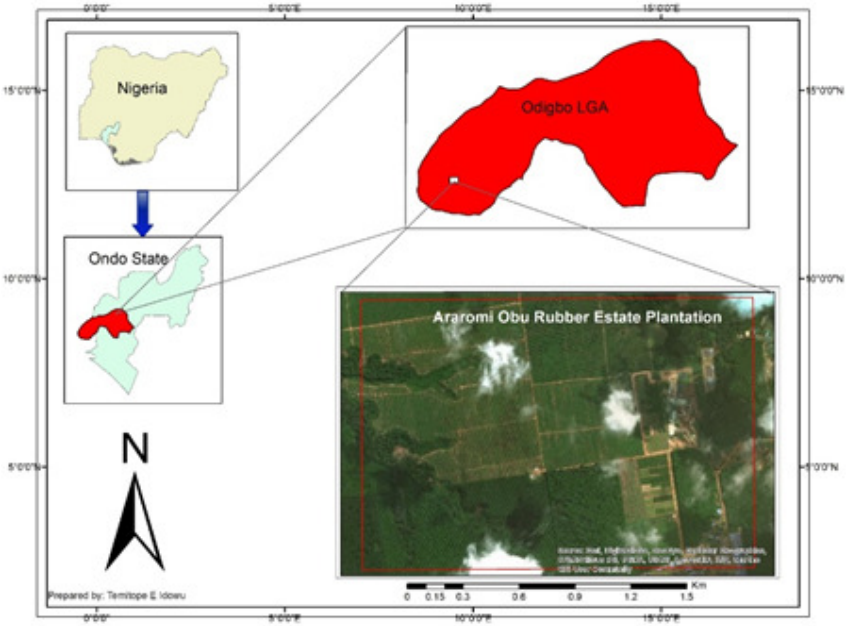

Figure 1: Map of the study area showing rubber estate plantation

2.2. Collection of Samples

Rubber latex processing wastewater samples were collected at the milling point into distinct sampling bottles, each of 100 Cl capacity in Rubber Estate, Araromi Obu. The sampling bottles were properly cleaned and sterilized before taking the samples. The bottles were thereafter kept in a cool dry place before being taken to the Central Postgraduate Research Laboratory, Federal University of Technology, Akure (FUTA), Ondo State for examination. This sampling was carried out according to the standard procedure provided by the US Environmental Protection Agency (EPA) (Simpson 2017). The rubber latex processing wastewater parameters were determined in accordance with standard methods for the examination of water and wastewater (American Public Health Association 2012).

2.3. Preparation of the PKS Sample

The PKS samples obtained from the study area were thoroughly washed with hot water to remove oil and soil particles. The washed PKS samples were thereafter sundried. The PKS was pounded with mortar and pestle to obtain even-sizes.

2.4. Carbonisation

Dried samples of the PKS were loaded in a stainless steel box and covered with lid to achieve an inert condition during carbonisation. The box was thereafter placed in a muffle furnace. At the start of the carbonisation process, the temperature was regulated to 300 °C and this temperature maintained for 30 minutes. The temperature was later increased to 500 °C and kept constant for the next hour. The char formed was allowed to cool down in the furnace for another 1 hour for the carbonisation to complete before being subsequently crushed with mortar and pestle. The crushed char was sieved to obtain a particle size range of

0.373 - 0.841 mm and used as the granular form of the PKS activated carbon. The powdered carbon (<0.1 mm) was obtained from the PKS by grinding the already formed char in the ball milling machine and sieved with ASTM 80 mesh sieve size. This procedure was repeated to obtain enough carbonised PKS samples for the experiments.

2.5. Chemical Activation

The char formed was soaked in hydrochloric acid (acid to char ratio of 1:1 by mass) and stirred for 24 hours under room temperature. The HCl was thereafter drained and the resulting residue was oven dried at 105 ^{o}C for 12 hours. The dried sample was placed in a muffle furnace and carbonized at 500 °C for 30 minutes. The sample was allowed to cool in the furnace. The activated material was neutralized with distilled water. The neutralized PKS activated carbon was oven dried at 105 ^{o}C for 24 hours, cooled at room temperature before storage in an air-tight container. This activation regime was also done on the grinded char to achieve the PPKSAC.

2.6. Adsorption of the Contaminants by Fixed Bed Technique

The fixed bed adsorption technique comprises of a well cleaned container which served to store the rubber latex wastewater sample and placed at a height just above a glass column loaded with GPKSAC such that the wastewater sample flows from it under gravity via a connecting pipe with valve into the column. A cotton wool was placed at the exit point of the column to prevent the discharge of activated carbon particles along with the treated rubber latex wastewater sample into a receiver at a predetermined flow rate of 0.50, 0.75 and 1.00 mL/min through the bed at different experimental conditions. The treated liquid samples were collected at the outlet at 1-hour interval for 4-hours. The procedure was also repeated for the PPKSAC and the samples taken for analysis in accordance with standard methods for the examination of water and wastewater (American Public Health Association, 2012).

2.7. Batch Adsorption Analysis

The batch adsorption analysis was carried out to determine the effect of adsorbent dose on COD removal. The test was done at room temperature using predetermined dose of 2, 3, 5 and 10 g of the PKS activated carbon placed in three different 250 cm^3 beaker containing 100 cm^3 of the rubber latex wastewater sample and shaken continuously at 300 rpm for 3 hours. The beaker content was taken from the filtered with 0.45 µm filter paper. The experiment was carried out with GPKSAC and PPKSAC at separate experimental procedures and thereafter analyzed. The sorption efficiency of the GPKSAC and PPKSAC was calculated using Equation 1:

$$\text{Sorption efficiency } = \frac{C_0 - C_e}{C_0} \times 100 \quad (1)$$

Where C_0 is initial concentration of pollution in the solution (mg/L), C_e is final concentration of in the solution (mg/L)

The concentrations retained in the adsorbent phase (q_e) were determined according to the mass balance using the following relationship:

$$q_e = (C_0 - C_e) \times \frac{V}{m} \quad (2)$$

Where m is mass of adsorbent (g/L), v is volume of solution (L).

2.8. Adsorption Isotherm

Adsorption isotherms reveal the interaction between the adsorbate and the pollutants to be removed. Several models are used for the description of the adsorption data of which the Freundlich and Langmuir models are the most commonly used ones. The Freundlich equation is expressed in the linear form as follow:

$$\text{Log}q_e = \text{Log}\, K_F + \frac{1}{\text{n}}\text{LogC}_\text{e} \quad (3)$$

K_F is the Freundlich constant and 1/n as the slope of the plot of Log q_e versus Log C_e

The Langmuir isotherm model assumes that adsorption occurs on a homogenous layer with equal surface energy spread. It is represented mathematically as:

$$\frac{\text{Ce}}{q_e} = \frac{1}{Klq_m} + \frac{\text{Ce}}{q_m} \quad (4)$$

q_m is the maximum amount of adsorbate per unit mass of adsorbate (mg/L) and K_L is the Langmuir constant. Langmuir equilibrium parameter (R_L) is the separation factor which expressed the favorability or otherwise of the isotherm. It is expressed as:

$$\text{R}_\text{L} = \frac{1}{1+ KlCo} \quad (5)$$

The isotherm is favorable if 0< R_L<, unfavorable if R_L>1, linear if R_L = 1 and irreversible if R_L = 0.

2.9. Adsorption Kinetic Models

The adsorption kinetic models provide insight for the rate of adsorption and design of a suitable adsorption mechanism using the data derived from the adsorption process. The pseudo-first order and pseudo-second order kinetic models were employed in the study. The pseudo-first order equation is represented linearly as:

$$\text{Log}\,(q_e\text{-}q_t) = \text{Log}\, q_e + \text{K}_1\text{t} \quad (6)$$

K_1 is the pseudo-first order rate constant (min^{-1}), and q_t is the amount of adsorbate adsorbed at time t (mg/g)

The pseudo-second order equation is represented as:

$$\frac{t}{q_e} = \frac{1}{\text{K2}} + \frac{1}{q_e}t \quad (7)$$

K_2 is the pseudo-second order rate constant (min^{-1})

2.10. SEM and FTIR Analysis of Palm Kernel Shell Activated Carbon

The morphology and internal pore structure characteristics of the PKS activated carbon was analyzed by scanning electron microscope (SEM; Jeol JSM- 6480LV, 30 kV). Fourier transform infrared spectroscopy (FTIR) analysis was also carried out to reveal the surface functional groups present in of PKS.

2.11. Recyclability Test

A recyclability experiment was carried out on the PKS. The GPKSAC was used for the test by subjecting 10 g dosage which yielded the optimum removal percentage (%) of COD to batch adsorption test of five cycles of adsorption and regeneration. The used GPKSAC was filtered out, washed under running distilled water and oven dried at 100 ^oC for 12 hours. The PKS activated carbon was used over five cycles.

3. RESULTS AND DISCUSSION

3.1. Characterization of the PKS Adsorbent

The surface texture of PKS activated carbon exhibited a well-developed porous surface at high magnification for effective fluid movement (Figures 2 and 3) as further explained in Ezzuldin *et al.* (2019). Omri and Benzina (2012) reported that the large irregular cavity in the PKS activated carbon surfaces was generated from the powerful attack of the reagent during activation.

The FTIR spectra of the granular and powdered PKS is illustrated in Figure 4. The small peaks between 3728 and 3027 cm^{-1} are traceable to the presence of hydroxyl functional group. The most identifiable characteristic peaks occur in the middle of 1700 and 1131 cm^{-1} which corresponds to C=O stretching in

carboxylates, ketones, and esters (Ajibade *et al*., 2021b). Also, the band at 781 cm^{-1} observed in the spectra revealed out of plane C-H functional group in the presence of calcium carbonate (Abatan *et al.,* 2020).

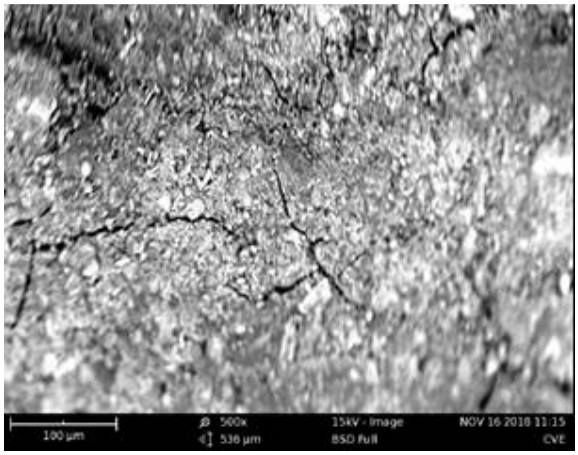

Figure 2: SEM PKS activated carbon image scale: 100µm

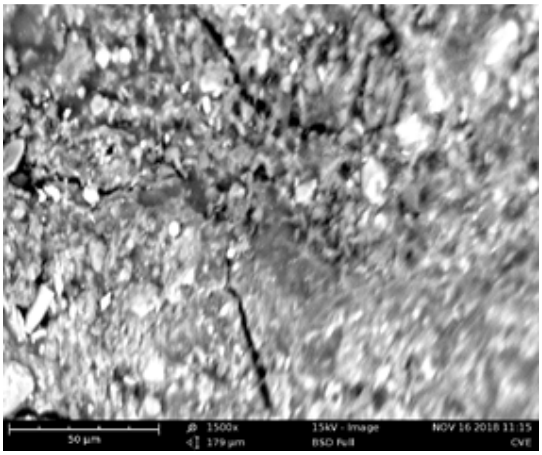

Figure 3: SEM PKS activated carbon image scale: 50µm

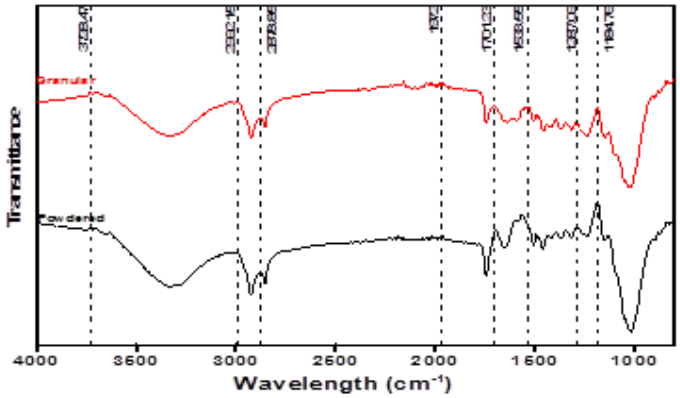

Figure 4: PKS FTIR spectra for GPKSAC and PPKSAC

3.2. Physicochemical Test on Rubber Latex Effluent

The result of the physicochemical test conducted before and after treatment of the rubber latex processing effluent with the fixed bed adsorption technique are presented as follow.

3.2.1. Treatment of rubber latex effluent by activated carbon at regulated flow rate

The results obtained when rubber latex processing wastewater was treated with GPKSAC and PPKSAC are presented in Tables 1 – 3. In Table 1, a flowrate of 0.5 mL/min was maintained while 0.75 mL/min and 1.0 mL/min flowrates were maintained in Tables 2 and 3 respectively. The flow rate does not have major impact on the treatment quality. The pH value of the effluent before treatment in Table 1 was 5.77 which is below the limit (pH 6-9) set by WHO and NESREA and indicates that the effluent was acidic as reported in Ramanan and Vijayan (2016). The pH of the rubber latex processing wastewater after treatment with the GPKSAC and PPKSAC within 2-4 hours fell between the range 6.19 - 7.65 which is between the limit (pH 6-9) set by WHO (2006) and NESREA (2009).

When compared with the effluent values before treatment, the same optimum performance of BOD removal (78%) was achieved at flowrate of 0.5 mL/min and 0.75 mL/min by the PPKSAC at the 4th hour of treatment (Table 2). However, 76% removal efficiency could only be achieved when a flow rate of 1.0 mL/min was

maintained by the GPKSAC for BOD removal from the rubber latex processing wastewater (Table 3). Likewise, the percentage removal efficiency of TSS was high with approximate value of 97% observed to be maintained by PKS activated carbon at flow rate of 0.5 mL/min and 0.75 mL/min (Table 1-2). Analysis also shows that the removal efficiency of ammonium nitrogen peaked at the 0.5 mL/min flow rate of treatment with the PPKSAC achieving 73% removal efficiency at the 4th hour of treatment (Table 1) implying the presence of unsaturated site on the PKS activated carbon ready for adsorption.

Table 1: Treatment by PKS activated carbon at 0.50 mL/min

Parameter	WHO standard	NESREA permissible limit	Before treatment	Effluent after treatment							
				1 hour		2 hours		3 hours		4 hours	
				GPKSAC	PPKSAC	GPKSAC	PPKSAC	GPKSAC	PPKSAC	GPKSAC	PPKSAC
pH	6-9	6-9	5.77	7.65	6.19	7.21	7.35	7.06	7.02	7.06	7.01
Temperature (°C)	-	40	29.00	29.00	29.00	29.00	29	29.00	29	29.00	29
BOD (mg/l)	60	30	52.30	14.70	11.42	12.60	12.10	12.20	12.10	11.70	11.60
COD (mg/l)	150	-	504.00	175.00	115.00	181.00	146.00	181.00	135.00	184.00	136.00
Total suspended solids (TSS) (mg/l)	60	30	378.00	12.60	12.30	11.60	10.90	11.30	11.00	10.00	10.90
Total dissolved solids (TDS) (mg/l)	1,500	2,000	257.00	35.20	30.70	79.80	65.90	82.30	66.30	83.00	66.60
Turbidity (NTU)	-	-	16.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hardness (mg/L)	-	-	33.00	5.40	5.10	5.50	5.10	5.50	5.30	5.70	5.50
Alkalinity (mg/L)	-	-	200.00	10.50	10.50	10.40	9.80	10.40	9.60	10.50	9.8 0
Sulphates (mg/L)		500	20.11	1.51	1.60	1.38	1.49	1.37	1.39	1.26	1.39
Ammonium nitrogen (mg/L)	-	-	16.80	5.60	4.90	5.10	5.00	4.90	4.90	4.80	4.60
Total nitrogen (mg/L)	-	-	25.00	4.80	3.60	3.60	2.50	3.70	2.70	2.90	2.30
Chloride (mg/L)	350	600	149.40	23.00	19.60	16.50	12.70	14.60	12.60	14.50	12.60
Odour	-	-	Offensive	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless
Colour	-	-	Yellowish	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear

Table 2: Treatment by PKS activated carbon at 0.75 mL/min

Parameter	WHO standard	NESREA Permissible limit	Before treatment	Effluent after treatment							
				1 hour		2 hours		3 hours		4 hours	
				GPKSAC	PPKSAC	GPKSAC	PPKSAC	GPKSAC	PPKSAC	GPKSAC	PPKSAC
pH	6-9	6-9	5.77	7.61	6.21	7.24	7.32	7.05	7.11	7.05	7.00
Temperature (°C)	-	40	29.00	29.00	29.00	29.00	29.00	29.00	29.00	29.00	29.00
BOD (mg/L)	60	30	52.30	14.90	13.47	12.80	12.70	12.30	12.60	11.90	11.30
COD (mg/L)	150	-	504.00	178.00	116.00	182.00	139.00	183.00	152.00	184.00	158.00
Total suspended solids (TSS) (mg/L)	60	30	378.00	12.80	12.70	11.70	11.30	11.90	11.40	11.00	11.30
Total dissolved solids (TDS) (mg/L)	1,500	2,000	257.00	35.90	31.20	80.60	69.30	81.40	68.50	83.50	70.40
Turbidity (NTU)	-	-	16.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hardness (mg/L)	-	-	33.00	5.40	5.10	5.60	5.30	6.80	5.30	7.00	6.00
Alkalinity (mg/L)	-	-	200.00	10.70	10.40	10.40	10.50	10.60	10.40	10.60	10.60
Sulphates (mg/L)		500	20.11	1.77	1.60	1.60	1.59	1.64	1.57	1.59	1.48
Ammonium nitrogen (mg/L)	-	-	16.80	5.50	5.00	5.20	5.00	4.80	4.70	4.80	4.80
Total nitrogen (mg/L)	-	-	25.00	5.60	3.90	4.80	4.20	4.60	4.10	4.20	3.80
Chloride (mg/L)	350	600	149.40	23.00	19.50	16.60	12.70	15.10	12.70	14.80	13.00
Odour	-	-	Offensive	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless
Colour	-	-	Yellowish	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear

Table 3: Treatment by PKS activated carbon at 1.00 mL/min

Parameter	WHO standard	NESREA permissible limit	Before treatment	Effluent after treatment							
				1 hour		2 hours		3 hours		4 hours	
				GPKSAC	PPKSAC	GPKSAC	PPKSAC	GPKSAC	PPKSAC	GPKSAC	PPKSAC
pH	6-9	6-9	5.77	7.78	5.93	7.35	6.22	7.05	7.05	7.05	7.04
Temperature (°C)	-	40	29.00	29.00	29.00	29.00	29.00	29.00	29.00	29.00	29.00
BOD (mg/L)	60	30	52.30	15.40	15.2	13.20	13.60	13.10	13.90	12.80	13.10
COD (mg/L)	150	-	504.00	179.00	125.00	183.00	138.00	182.00	155.00	181.00	163.00
Total suspended solids (TSS) (mg/L)	60	30	378.00	13.20	12.90	12.80	11.60	12.60	11.60	12.30	11.20
Total dissolved solids (TDS) (mg/L)	1,500	2,000	257.00	39.60	33.60	82.60	72.50	82.90	73.60	86.40	80.10
Turbidity (NTU)	-	-	16.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hardness (mg/L)	-	-	33.00	5.70	5.20	5.70	5.40	6.20	5.40	6.90	5.50
Alkalinity (mg/L)	-	-	200.00	10.90	10.50	11.10	10.70	10.90	10.40	10.80	10.20
Sulphates (mg/L)		500	20.11	1.75	1.60	1.60	1.65	1.63	1.63	1.60	1.59
Ammonium nitrogen (mg/L)	-	-	16.80	6.10	5.20	6.20	5.10	5.70	4.60	5.80	4.70
Total nitrogen (mg/L)	-	-	25.00	5.00	4.00	5.00	3.90	5.10	3.90	4.80	3.70
Chloride (mg/L)	350	600	149.40	26.00	21.00	22.10	14.40	17.10`	13.90	16.80	13.30
Odour	-	-	Offensive	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless
Colour	-	-	Yellowish	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear

Similarly, an appreciable level of removal efficiency was achieved for chloride treatment at 0.5 mL/min (Table 1). The GPKSAC efficiently removed 90% chloride contamination at the 3rd and 4th hour of treatment,

while the PPKSAC activated carbon obtained a higher 92% removal efficiency at the 4th hour of treatment. Treatment at 0.75 mL/min flowrate also yielded the same values of high chloride removal efficiency by the GPKSAC and PPKSAC (Table 2-3). As regard odour and colour removal, the PKS activated carbon produced removed the offensive odour and also changed the yellowish colour of the rubber latex processing wastewater to a clear liquid (Table 1-3). This positive trend shows the adsorptive capacity of the PKS activated carbon to remove the organic and inorganic contaminants present in the rubber latex processing wastewater. This result supported the research conducted by Ademiluyi *et al.* (2009).

3.2.2. COD Batch Adsorption Test

The batch adsorption test carried out on the rubber latex processing wastewater was to ascertain the equilibrium capacity of the PKS activated carbon. The percentage adsorption efficiency of COD by the GPKSAC and PPKSAC are presented in Table 4. The initial COD concentration was 439.78 mg/L. At different carbon dosages of 2 g, 3 g, 5 g and 10 g, the GPKSAC achieved 85.19%, 86.18%, 88.35% and 90.75% respectively of COD adsorption efficiency. The same carbon dosages of 2 g, 3 g, 5 g and 10 g were also maintained to test the adsorption efficiency of the PPKSAC for COD removal. The PPKSAC produced glaringly improved adsorption efficiencies of 88.89%, 90.01%, 91.01% and 91.71% respectively. The use of the GPKSAC as well as the PPKSAC thus reveal decrease in organic pollutants content with increasing PKS activated carbon dosage. This result when compared, competes favourably with conventional and advanced technology for natural rubber wastewater treatment. Massoudinejad *et al.* (2015) used a combination of physicochemical and ozonation process to treat natural rubber industry wastewater to achieve a COD reduction of 90.6% at optimum condition. Rosman *et al.* (2013) also demonstrated the capabilities of the aerobic granular sludge to be 96.5% efficient for COD removal from rubber wastewater treatment while Mohammadi *et al.* (2010) conducted a research on the electrochemical treatment of rubber wastewater. The study produced an efficiency of 99.9% COD removal.

Table 4: Percentage adsorption efficiency of COD

Mass (g)	Initial COD value (mg/L)	Final COD value (mg/L)		% Reduction	
		GPKSAC	PPKSAC	GPKSAC	PPKSAC
2	439.78	65.15	48.86	85.19	88.89
3	439.78	60.78	43.93	86.18	90.01
5	439.78	51.24	39.55	88.35	91.01
10	439.78	40.68	36.45	90.75	91.71

3.3. Adsorption Isotherms

The parametric values in Table 5 were obtained using the Freundlich linear equation were used to compare the differences obtained between the GPKSAC and PPKSAC. The value of 1/n corresponding to the slope and K_F as the intercept obtained for adsorption of most organic compounds by activated carbon was less than one. The values of n (>1) for both GPKSAC and PPKSAC boost the capability of the PKS as an excellent adsorptive material. The values of *1/n* decreasing towards zero with the PPKSAC further shows the heterogeneity of the interfacial network. Also, when compared, the K_F value of the PPKSAC was slightly greater than that of the PPKSAC indicating that it has better adsorptive capabilities.

Table 5: Parametric result of Freundlich linear equation

Equation parameter	GPKSAC	PPKSAC
n	4.808	5.181
1/n	0.289	0.188
K_F	0.3587	0.402
R^2	0.7873	0.7297

The Langmuir isotherm gives information about the adsorption capacity of the adsorbent presents. As shown in Table 6, the adsorption data fitted the Langmuir isotherm model more appropriately because the correlation coefficient (R^2) values obtained for both the GPKSAC (0.9643) and PPKSAC (0.9431) close to

unity and also higher than the R^2 values obtained from the Freundlich isotherm model which are 0.7873 and 0.7297 respectively for granular and powdered forms, suggesting a uniform site of adsorption of contaminant on the PKS activated carbon. Values of 0.00175 and 0.00185 were the separation factors (R_L) of the granular and powdered PKS activated carbon respectively. These values were found to be favorable ($0<R_L<1$) and makes the PKS activated carbon excellent in nature as an adsorbent.

Table 6: Parametric result of Langmuir linear equation

Equation parameter	GPKSAC	PPKSAC
q_m	5.952	6.254
K_L	1.304	1.233
R_L	0.00174	0.0019
R^2	0.9643	0.9431

3.4. Adsorption Kinetics

Figure 5 and 6 show a plot of the linearized form of the pseudo-first-order and pseudo-second-order model. The pseudo-first-order and pseudo-second-order parameters obtained for adsorption by the GPKSAC and PPKSAC are presented in Table 7. The R^2 value obtained for the PPKSAC (0.9956) was slightly higher than that obtained from the GPKSAC (0.9834). The q_e value gotten for PPKSAC doubled that of the GPKSAC. This is necessitated by the higher surface area present in the PPKSAC and abundant of active sites available for adsorption. The pseudo-second order R^2 values of 0.9981 (powdered) and 0.9895 (granular) are much higher than the values obtained in the pseudo-first-order model. The pseudo-second-order most excellently describe the kinetic data adsorption process obtained as both data of R^2 gotten are higher than the pseudo-first-order values and also close to unity ($R^2 = 1$).

Table 7: Adsorption kinetics of the GPKSAC and PPKSAC

PKS activated carbon	Pseudo-first-order			Pseudo-second-order		
	q_e (mg/g)	K_1 (min^{-1})	R^2	q_e (mg/g)	K_2 (g/mg/min)	R^2
GPKSAC	2.230	0.028	0.9834		0.031	0.9895
PPKSAC	4.596	0.0387	0.9956		0.494	0.9981

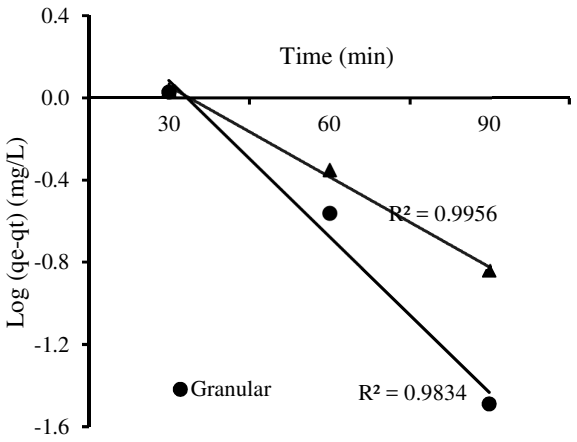

Figure 5: Pseudo-first-order for GPKSAC and PPKSAC

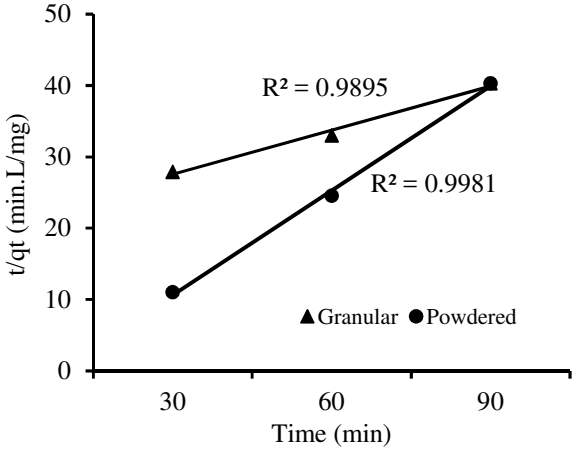

Figure 6: Pseudo-second-order for GPKSAC and PPKSAC

3.5. Recyclability of the PKS Activated Carbon

The granular PKS activated carbon was recycled to ascertain its regenerative capability and potential for future use. The result illustrated is Figure 7 shows a steady and excellent performance of adsorption by the

regenerated granular PKS activated carbon. The PKS maintained a COD removal percentage (%) above 90% in each cycle, making it an excellent adsorbent that can be used a sundry time before disposal.

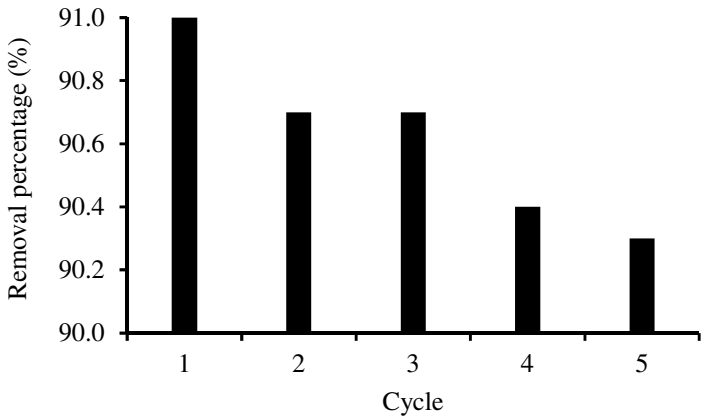

Figure 7: Recyclability of the PKS activated carbon

4. CONCLUSION

This research work has shown the usefulness and effectiveness of PKS as a source of producing activated carbon for industrial wastewater treatment. The PKS which is characterized by excellent physical properties for use in various engineering applications and as adsorbent in water treatment technology proved effective in the production of excellent activated carbon and in the removal of considerable amount of organic and inorganic contaminants in rubber latex processing wastewater. SEM image revealed high macropores network for effective fluid movement while the FTIR analysis revealed the surface functional groups responsible for the high adsorption capacity of PKS. The values of the coefficient of determination (R^2) indicated that the adsorption process was best explained by the pseudo-second-order kinetic and Langmuir isotherm models than the other models. The recyclability test indicates that the PKS activated carbon will maintain a high adsorptive capability after five cycles. The prepared palm kernel shell carbon can be utilized for pollutant removal from rubber latex wastewater before disposing to the soil or water.

5. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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