

Original Article

Performance of Ocimum Gratissimum Leaf Activated Carbon in Water Treatment

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Abstract - The study of Scent Leaf (*Ocimum gratissimum*) as a biomaterial is of great interest not only because of its nutritional, therapeutic, and pharmaceutical tendencies, but in its use as adsorbents in the removal of Turbidity, pH, Lead (Pb^{2+}), Chromium (Cr^{2+}), Cadmium (Cd^{2+}), Iron (Fe^{2+}), and *E. coli* in water samples used for consumption. Modified *Ocimum gratissimum* Leaf (OGL) was prepared by carbonizing the dry powdered material at three different temperatures of 350, 450 and 550 degrees Celsius and impregnated in a base (NaOH) to be developed into activated carbon, which was characterized using Fourier Transform Infrared (FT-IR) and Scanning Electron Microscopy coupled with Energy Dispersal Spectroscopy (SEM-EDS) in order to appraise their functional and morphological groupings. Fixed-bed column adsorption technique was used to assess the remediation potential of the adsorbents when in contact with adsorbate at different flow rates of 15, 30 and 50 ml/min, bed-thicknesses of 1, 2 and 3 cm: contact-time of 5, 15, 30, 45 and 60 mins. Response surface methodology based on Box Behnken Design (BBD) was used to evaluate the impact that the independent variables have on the adsorption capabilities of Turbidity, pH, Pb^{2+} , Cr^{2+} , Cd^{2+} , Fe^{2+} , and *E. coli* from well water. The optimum condition for maximum adsorption for the modified *Ocimum gratissimum* leaf activated carbon was a Flow rate of 46.39 ml/min, adsorbent bed thickness 2.866 cm, and contact time of 60 mins to effectively eliminate Cadmium to 100 %, Turbidity to 98 %, Chromium to 98 %, *E.coli* to 98%, Fe to 92 % and, Pb to 67 %, while reacted negatively to pH from the initial value of 7.32 to 10.081 (Highly Alkaline).

Keywords - Adsorption, Activated carbons, Fixed-bed column, *Ocimum Gratissimum*, Response surface methodology.

1. Introduction

The research for sustainable bio-degradable materials for use as activated carbon has increased during the past decades, largely due to its exceptional adsorption capabilities for use in the water/wastewater, air filtration and energy storage industry [1], [2].

The primary sources of water supply in underdeveloped nations, including Nigeria, are wells that draw groundwater [3][4]. The dependence on these sources is a result of the inaccessibility of government-supplied sources, their affordability and proximity to points of usage. Due to low knowledge of the health implications of low-quality potable water and the high cost of alternative treatments like boiling chlorination and ultraviolet (UV) light, most wells are consumed untreated, exposing users to potentially fatal water-borne illnesses like typhoid, dysentery, cholera, gastroenteritis, etc. The conventional methods of water treatment could not be afforded by the teeming population of developing countries, especially Nigeria; thus, there is a need for alternative means of treating water, especially domestic

ones. Research showed the possibility of using agricultural bio-materials in treating water [5,6,7]. Hence, this study investigated the practicability of employing readily available agricultural bio-material (i.e. plant), *Ocimum Gratissimum* Leaf (OGL), known as clove basil, sweet basil, tea bush, scent leaf, or fever plant, and traditionally recognized by different local names in Nigeria (Nupe: Tan- motsungi-wawagi; Ebirá: Ikeru; Hausa: Dai doya ta Gida; Yoruba: Efinrin Ajase; Ibo. Nchanwu), as adsorbent to remove toxic metals as well as bacterial pollutants linked to water pollution.

Activated carbon as adsorbent materials have traditionally been sourced from non-renewable fossil fuels [3] and [4]. However, the quest for regeneration and biodegradable materials, offering sustainable alternatives to traditional activated carbon materials, has led researchers to renewable sources such as agricultural waste, biomass, and organic matter [6], [7], [8]. These materials are believed to possess inherent porosity and surface chemistry, making them promising candidates for adsorptive applications. Additionally, their abundance, low cost, and ability to



sequester metals contribute to their attractiveness in waste management strategies [10]. The utilization of biomaterials such as activated carbon could significantly reduce the environmental problem footprint associated with conventional methods of treating water [2].

In the recent past, some researchers used activated carbons produced from agricultural bio-materials to remove toxic metals and bacterial pollutants linked with some wastewater. [11] achieved adsorption efficiency of 91.3% for Coliform bacteria removal in a water treatment plant using commercially sourced activated carbon. [12] achieved a 100 % adsorption efficiency of Cd (II) removal from wastewater using Albizia saman pod activated carbon (ASPAC). [13] also achieved above 95.0% removal efficiency of selected toxic metals using Carica papaya from mining wastewater. However, literature is very scarce on the use of OGL as activated carbon for water treatment.

This research investigated the performance of OGL-activated carbon as an adsorbent for the removal of Turbidity, pH, Pb²⁺, Cr²⁺, Cd²⁺, Fe²⁺, and E. coli from shallow well water obtained from Ado-Ekiti metropolis of Southwestern Nigeria.

2. Materials and Methods

Figure 1 shows the outline of the methods of this research work.

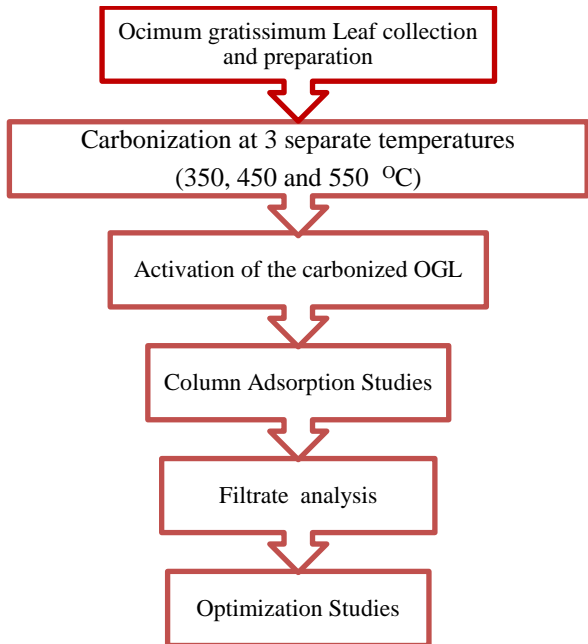


Fig. 1 Schematic diagram of the experimental stages

2.1. Collection and Preparation of Precursor Materials (Ocimum gratissimum leaf and well water sample)

Ocimum gratissimum Leaf (OGL) was collected from a local farm in Ado-Ekiti, Ekiti State Central Senatorial district, the Southwestern part of Nigeria, and identified in the

Agricultural & Bio-Environmental Engineering Department of the Federal Polytechnic Ado-Ekiti (See Plate 1). The leaves were plucked from the stem, washed with distilled water to remove dirt and soluble impurities, and oven-dried at (30 °C) for 5 hrs. The enhanced method proposed by [13], [14] and [15] was used. At the same time, the well water sample was used as the adsorbate, obtained through the grab method from a lined, covered hand-dug well sited within a clustered residential area in Ado-Ekiti metropolis, Ekiti State, Nigeria.



Plate 1. Ocimum gratissimum Leaf

2.2. Preparation of the Adsorbent

2.2.1. Carbonization Stage

Carbonization stage, in accordance with the enhanced method proposed by [13], [14] and [15], 500 gm of dried pulverized OGL was carbonized at three separate times in an enclosed programmable muffle furnace (Carbonite HTF 1700 model) at 350, 450, and 550 °C for 107, 145, and 210 minutes as shown in Plate 2. The carbonized OGL produced was washed continuously with distilled water until a pH value of 7 was attained; afterwards, oven dried at 30 °C for 2 hrs. and allowed to cool in a desiccator. After that stored for the activation stage.



Plate 2. Carbonization process

2.2.2. Activation Stage

Activation stage, carbonized OGL produced was poured into a tapered Erlenmeyer flask and activated by impregnating with 0.3 M NaOH at 9 g/l at an impregnation ratio of 1:3 (Activating agent: carbon), sealed and allowed to settle for 24

hrs. at room temperature (as shown in Plate 3). The outcome was washed with distilled water and sieved with a 10-micron filter paper, left to dry in an oven at 30 °C for 3 hrs. The dried adsorbents produced were stored in a desiccator in readiness for characterization studies, labelled as A (OGLAC-NaOH @ 350 °C, B (OGLAC-NaOH @ 450 °C, and C (OGLAC-NaOH @ 550 °C).



Plate 3. Impregnation of carbonized OGL in NaOH – Activation process

2.3. Characterization of the Adsorbents

2.3.1. The Fourier Transform Infrared Spectroscopy (FTIR) Examination

The FTIR to know the surface chemistry of the raw OGL and adsorbents (A, B and C) was determined using Infrared Spectrophotometer (Model Perkin Elmer 3000 MX spectrometer) and analysis was done automatically by the software (Spectrum spectroscopic software Win-IR Pro Version 3.0 with a peak sensitivity of 2 cm⁻¹) attached to the system. The spectra range required to capture the needed functional groups was estimated at 4 000.0 to 400.0 cm⁻¹. The adapted methods of [8] and [16] were adopted.

2.3.2. Scanning Electron Microscopy (SEM) Coupled with EDS

Model Leo Supra 50VP Field Emission, UK, was used to evaluate the surface morphology and elemental composition of the raw OGL and the prepared adsorbents to comparatively assess the pore's surface roughness, structure, and configurations before and after being activated for its potential use for water treatment purposes. This was accomplished by first employing a double-edged tape to spread the target sample particle over an aluminum stub, bombarding it with electrons, and then using an SEM apparatus to coat the surface with a platinum film. This was conducted in accordance with the enhanced method proposed by [17].

2.4. Well Water Sample Analysis

The enhanced method proposed by [18], was adopted in assessing the physicochemical and bacteriological parameters of the well water sample. DR 900 HACH Colourimeter and potable Hanna pH meter were used to measure the Turbidity and pH properties of the samples (on-site). Afterwards, the remaining parameters (Pb²⁺, Cr²⁺, Cd²⁺, and Fe²⁺ and E.coli)

were analyzed in the water laboratory of the Civil Engineering Department, Federal Polytechnic, Ado-Ekiti within 24 hours of sampling using the APHA (2012) standard methods. An Atomic Absorption Spectrophotometer (AAS) was used for the determination of Pb²⁺, Cr²⁺, Cd²⁺, and Fe²⁺ concentrations. At the same time, EMB agar, ethanol, petri dish, cotton wool, heating mantle, incubator and water bath heater were deployed for the bacteriological analyses (E. coli as the indicator) using the Pour plate method.

2.5. Column Adsorption Experimentation

Treatments of the well water using raw OGL, and the adsorbents (A, B and C) were carried out with column (fixed bed) adsorption method. The adsorption factors considered in the column adsorption set-up between the adsorbate (well water sample) and adsorbents are the flow rates (5, 15, 30 ml/min), bed thickness (1, 2 and 3 cm) and contact time (5, 15, 30, 45, and 60 mins) using the modified work of [12] and [19].

2.5.1. The effect of the Adsorbent Flow Rate

The effect of the adsorbent flow rate was investigated by allowing the column to receive adsorbate from a 1.5-L conical reservoir at the funnel (Plate 4). Three different flow rates of 5, 15 and 30 ml/min varied with the aid of a flow meter attached to the set-up was used for the experimental work, while other factors were kept constant. Filtrate at the outlet of the column was collected after passing through the adsorbent at regulated time intervals. The concentrations of the adsorbate and filtrate were studied before and after passing through the adsorbent bed to investigate the absorption activity of OGL-activated carbon.



Plate 4. Experimental set-up of column adsorption for the study

2.5.2. The effect of Adsorbent Bed Thickness

The effect of adsorbent bed thickness was assessed by using three different adsorbent bed thicknesses: 1, 2 and 3 cm. The adsorbent, at different depth thicknesses, remains in the column for a maximum contact time to simulate an allowable contact time for water treatment in a home environment, while other factors were kept constant. The performance of the bed

thickness was described by the removal efficiency of the adsorbents on Turbidity, Pb²⁺, Cr²⁺, Cd²⁺, Fe²⁺ and E. coli.

2.5.3. The effect of Contact Time

The effect of contact time was assessed by using a contact time of 5, 15, 30, 45, and 60 mins to evaluate the adsorption removal efficiency of OGLAC for the removal of Turbidity, Pb²⁺, Cr²⁺, Cd²⁺, Fe²⁺, and E. coli. The adsorbate was allowed contact with the adsorbent at a varying bed thickness and fixed contact time. For each of the contact times, the filtrate collected was assessed for its removal Efficiency. Removal Efficiency (RE) in percentage (%) was calculated using equation (1).

$$RE = (C_0 - C_e) / C_0 \times 100\% \quad (1)$$

C₀ and C_e are concentrations before and after OGLAC treatment.

2.6. Adsorption Optimization Studies

The statistical evaluations of the adsorption data were performed using Design Expert software version 11 - DOE v11 (Stat-Ease, 2018). The study's dependent variables (adsorbate flow rates, adsorbent bed thickness and contact time) and independent variables (Turbidity, Pb²⁺, Cr²⁺, Cd²⁺, Fe²⁺, and E. coli) were investigated. The outcome from the trials conducted using the dependent variable and independent variables were added to BBD to generate a random number of experimental runs. To identify the ideal conditions and carry out the optimization process, DOE v 11 was used to evaluate

the experimental data, compute the expected responses, and create the factorial regression model. Regression analysis and three-dimensional (3D) response surface plots of the dependent variable and each of the seven independent variables were used to estimate the ideal removal efficiencies.

3. Results and Discussion

3.1. Concentrations of selected Parameters in the Well Water Sample before Treatment

The initial concentration of the selected physical, chemical, and bacteriological parameters of the water sample used as the adsorbate for the experimentation is shown in Table 1. The raw well water used had a turbidity value of 35 NTU conflicting to the acceptable limit of 5 to 15 NTU, Pb²⁺ was 1.259 as opposed to the permissible limit of 0.01, Cd²⁺ was 1.077 as divergent to 0.003, Fe²⁺ was 0.937 as contrasting to 0.3, and E. coli was 65 CFU/ml as different to 0 count. None of the parameters selected met the WHO (2009) standards for drinking water quality prior to treatment. This suggested that the well water may be contaminated, necessitating further study into its treatment.

3.2. Physical properties of the raw and produced OGLAC

Plate 5 shows the pictures of raw OGL and the OGLAC (A, B and C) adsorbents. Raw OGL has a brownish colouration with a mint scent and bitter in taste, while the OGLAC A, B and C were darkish in colour, coarse and odourless. They are also tasteless.

Table 1. Selected physical, chemical and bacteriological parameters of the well water sample

S/No.	Parameters	Unit	Concentration	[22] Standards
1.	Turbidity	FAU	35	5.00 – 15.00
2.	pH	-Log[H ⁺]	9.7	6.5 – 8.5
3.	Pb	Mg/l	1.259	0.01
4.	Cr	Mg/l	0.937	0.05
5.	Cd	Mg/l	1.077	0.003
6.	Fe	Mg/l	0.937	0.3
7.	E. coli	CFU/ml	65	0

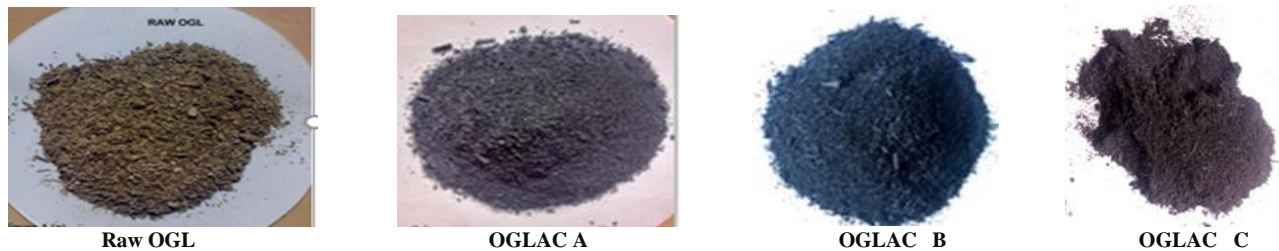


Plate 5. Raw OGL and OGLAC (A, B and C) adsorbents

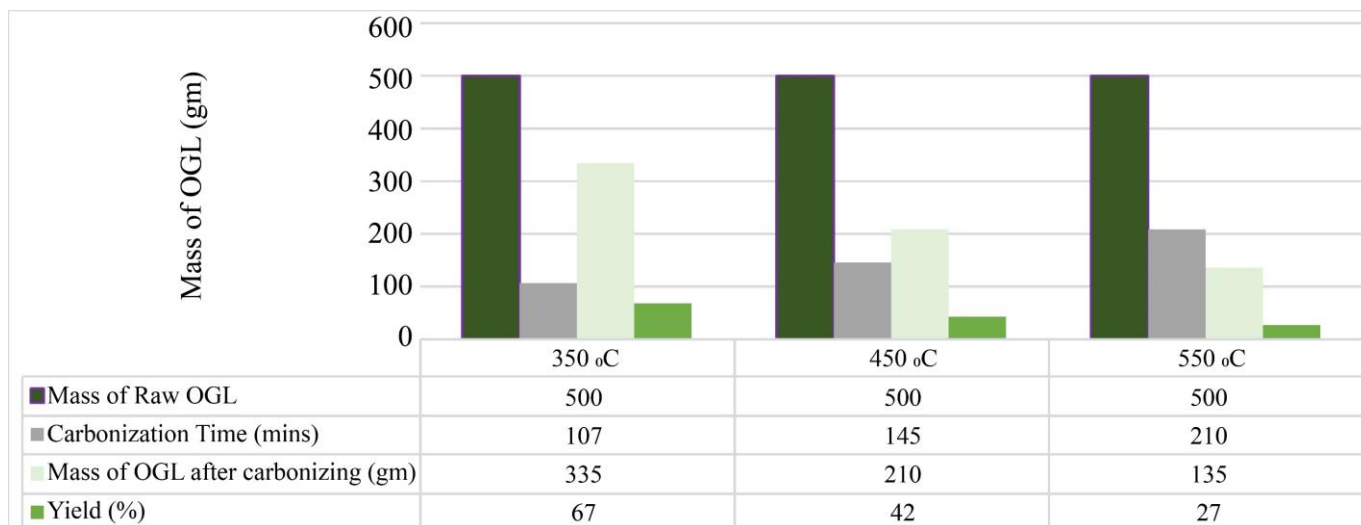


Fig. 2 Percentage yield of carbon after pyrolysis process at different temperatures

Table 2. Changes in IR Spectra of the raw OGL and OGLAC adsorbents

S/No.	IR Peak				Band Class	Bond Type	Remark
	RAW OGL	A	B	C			
4	-	3406 - 3850.6			Aliphatic primary amine, Alcohols, phenols and carboxylic acids`	Normal polymeric O-H Stretch; Non-bonded O-H Stretch	Appeared
5	2925.3	2912 - 2926			Alkane	C-H Asy/symmetric	Remained
7	-	2351 - 2356			Thios	S-H Stretch	Appeared
8	-	1709.38 - 1714.19			Carboxylic acid	C=O	Appeared
9	1602	1601 - 1605			Conjugated Alkene	O-H bending	Remained
10	-	1442 - 1447			Carboxylic acid	O-H bending	Appeared
11	1377	1372 - 1376			Aliphatic nitro compounds	O-H Stretch	Remained
12	1029	1034			Primary Amine	C-O Stretching	Disappeared
13	-	722	-	-	Aliphatic choro compounds	C-Cl Stretch	Remained

3.2.1. Effect of Temperature on Percentage Yield (%)

Figure 2 as the intensity of heat varied from 350, 450, and 550 °C, the mass of carbon retained was 338, 210, and 135 gm(s), while the percentage yield decreased from 67 percent to 27 percent. This is consistent with the findings of [20], who submitted that the temperature at which carbonization occurs can impact the yield. However, the resulting product may be purer in terms of carbon content but less in quantity.

3.3. Results of Characterization of the Raw OGL and Produced Adsorbents using FTIR

Table 2 and Figures 3 to 6 show the FTIR spectra of the raw OGL and adsorbents A, B and C to assess the possibilities of shifts in IR peaks. The IR spectra of raw OGL were compared with that of A, B and C. The actual behaviour of the carbonizing temperatures and activating chemicals utilized to

promote the adsorbents' performances for possible adsorption purposes are described by modifications in peak positions. From Table 2 and Figure 3, aliphatic primary amines, alkanes, alkenes, sulfonates, and anhydride compounds were revealed in the raw OGL spectrum at peaks ranging between 3406 and 1030 cm⁻¹. The peak at 3406 cm⁻¹ is ascribed to the presence of aliphatic primary amine (N-H stretching), while the alkane (C-H) group is symmetrically and asymmetrically stretched at 2925.3 cm⁻¹. The presence of Sulfate (S=O stretching) causes a faint band to be seen at 1377 cm⁻¹, whereas Primary Amine (N=H) is shown at 1029 cm⁻¹. Conjugated (C=C stretching) groups can be seen at 1602 cm⁻¹.

When FTIR spectra of raw OGL and adsorbent A were compared, changes in IR spectra were noted between the raw OGL and OGLAC-NaOH @350 °C. Table 2 and Figure 4

show bond types to be O-H stretch, normal polymeric, C-H asymmetric/symmetric stretch, S-H stretch, O-H bending, and C-Cl stretch, which appeared at 3850.6, 3368, 2919, 2351, 1443, and 722.27 cm^{-1} . C=O and C-O Stretching bond types remained at 1709.38, 1602, 1375.5, and 1029 cm^{-1} ; while N-H stretching bond type disappeared at 3407 cm^{-1} .

A comparison between the FTIR spectra of raw OGL and adsorbent B (Table 2 and Figure 5) depicted that the C=C bond moved downward to 1626 cm^{-1} . N-H, C-H Asymmetric/symmetric, C=C, and S=O Stretching

disappeared. While C-O Stretching at 1034 cm^{-1} persisted, S-H Stretch Thios, O=C=O Stretching, and O-H bending at 2356, 1714.19, and 1447 cm^{-1} all appeared. FTIR comparison between the raw OGL and adsorbent C brought about a shift downwards of C-H asymmetric/symmetric and C=C stretching at 2924 and 1601 cm^{-1} , while stretching at 1602, 1380, and 1029 cm^{-1} for C=C, S=O, and C-O disappeared. O-H stretching, O-CH₃ bending methyl ether, S-H stretch thios, O-H bending, and S=O stretching appeared, but N-H stretching at 3406 remained unshifted.

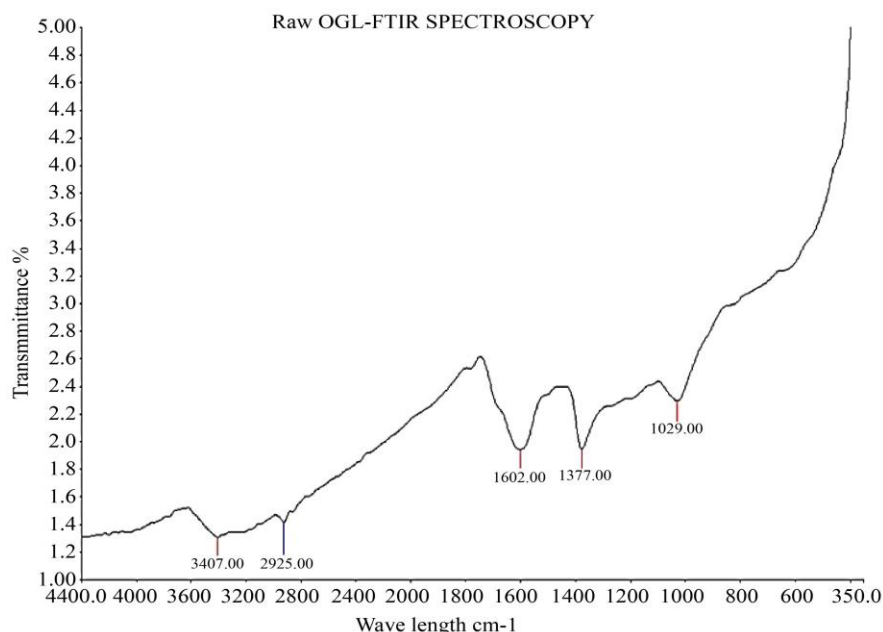


Fig. 3 Surface Chemistry – FTIR of Raw OGL

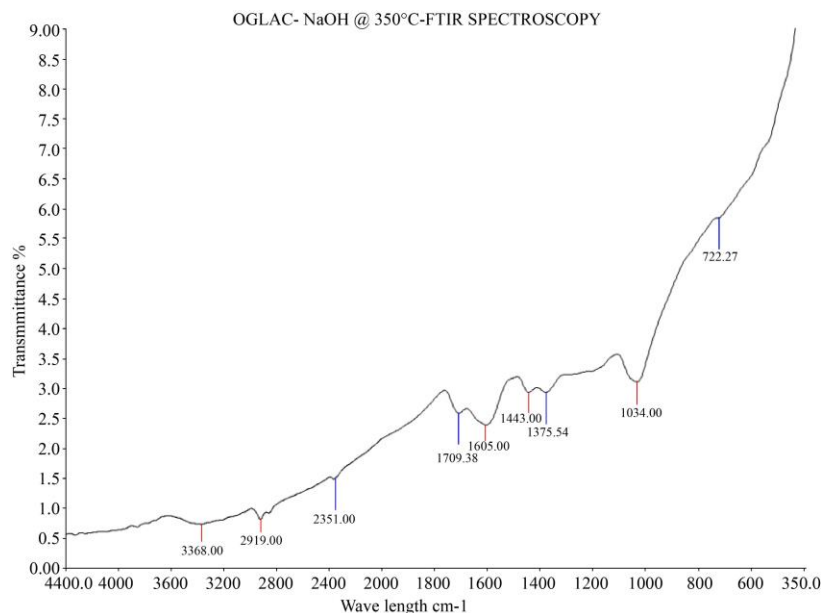


Fig. 4 Surface Chemistry – FTIR of OGLAC- NaOH @ 350°C

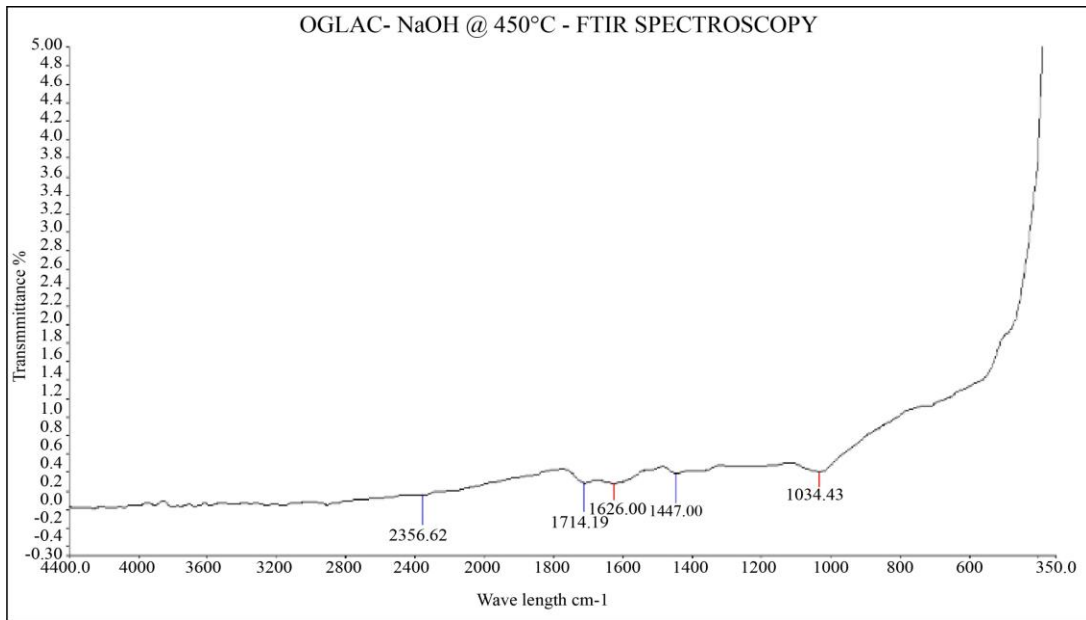


Fig. 5 Surface Chemistry – FTIR of OGLAC- NaOH @ 450 °C

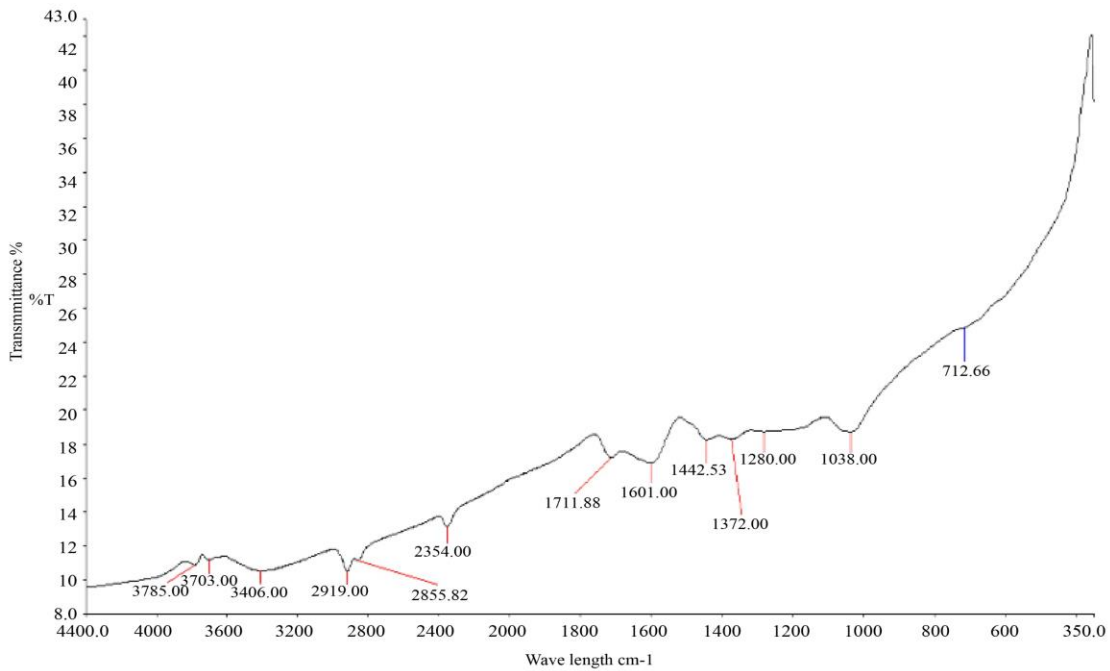


Fig. 6 Surface Chemistry – FTIR of OGLAC- NaOH @ 550 °C

In conclusion, following the varied carbonizing temperatures alkali treatment of OGL, changes in FTIR spectra confirmed their effects on the raw OGL. The observations of the FTIR spectra revealed that some of the peaks, when compared to the raw OGL shifted upward, others shifted downward, some outrightly disappeared, while the rest remained unaffected.

These changes in peak values are the result of the carbonization and activation processes, which brought about chemical bonds among the functional groups that were present in the OGL. This agrees with the work of [22].

3.4. Results of Characterization of the Raw OGL and Produced Adsorbents using SEM

Plates 6 - 9 show the SEM micrographs of the raw OGL and the three activated carbons (A, B and C) to analyze the surface pore structure of the adsorbents and determine which will be the ideal adsorbent for removing contaminants. When the raw OGL micrograph (Plate 5) was compared to the other micrographs (Plates 6, 7 and 8), the adsorbents created a more porous interphase inside the material's surface. These pores are crucial passageways for an adsorbent's microporous nature to absorb different pollutants. Due to the breakdown of

lignocellulosic materials as the temperature rises and modification with the activating agent, there are significant pores with numerous rough, uneven cavities scattered throughout the surface of the adsorbents.

The adsorbents have developed pores because volatile chemicals evaporate. Due to the loss of carbon components in CO and CO₂ forms, the rise in reaction rate during the activation phase led to "burn off," which generated excellent pores. The physicochemical treatments led to the production of porous adsorbents. Increased adsorbate uptake followed, which was helpful in the adsorption processes [20, 21].

On the surfaces of adsorbents, there were numerous big pores with honeycomb-like geometries. These results demonstrate that the activating agents (NaOH) were successful in generating more heterogeneous and well-developed surface structures than previously observed in the raw OGL. These pores offered a suitable surface for the trapping and adsorption of pollutants. From the three adsorbents were prepared from raw OGL, using diverse temperatures (350, 450, and 550 °C) and NaOH activating agent.

Adsorbent C was the most reactive as observed through the characterization test carried out. More functional groups appeared during the pyrolysis because of an increase in carbonizing temperatures, supporting the works of [23] and [24]. At the same time, the morphological surface produced a more porous surface indicative of their suitability for the trapping of pollutants. Hence, the adsorbent C, produced at 550 °C was used for the column adsorption experiments.

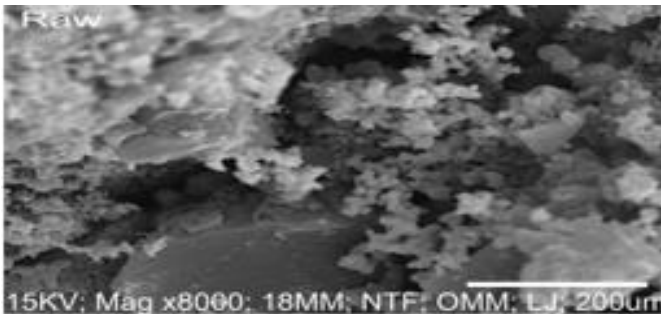


Plate 6. Surface Morphology of Raw OGL using SEM

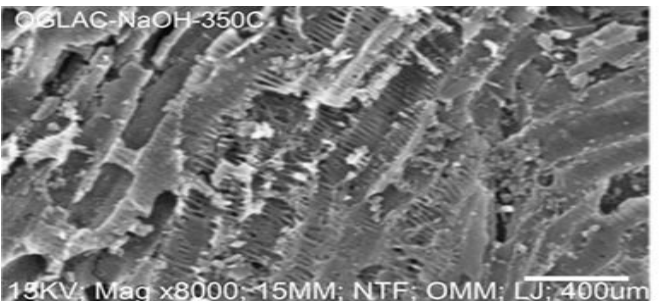


Plate 7. Surface Morphology of OGLAC- NaOH @ 350 °C using SEM

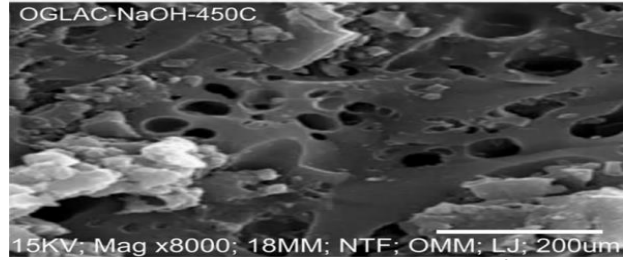


Plate 8. Surface Morphology of OGLAC- NaOH @ 450 °C using SEM.

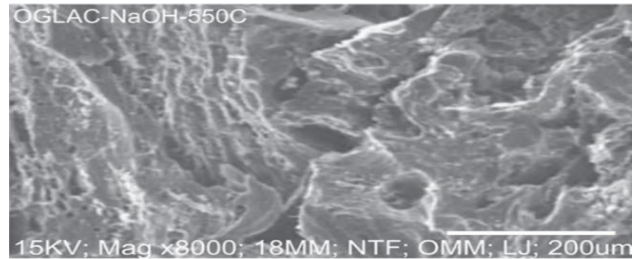


Plate 9. Surface Morphology of OGLAC- NaOH @ 550 °C using SEM

3.5. Results of the Column Adsorption Experimentation

This section evaluates the results of the impact of the three adsorption factors (Flow rate, adsorbent bed thickness and contact time) on the selected water quality parameters such as Turbidity, Pb²⁺, Cr²⁺, Cd²⁺, Fe²⁺, and E. coli. Table 3 shows the Removal Efficiency (RE) of the prepared adsorbent (OGLAC-NaOH @550 °C).

3.5.1. Effects of Adsorbate Flow Rate

As flow rates increased from 15, 30 and 50 ml/min, while other variables such as Bed thickness and Contact time were kept constant (Table 3), the Removal Efficiency (RE) of the adsorbent decreased. This is consistent with the findings of [16] that a relative increase in volumetric flow rate will not provide adequate time for the adsorption equilibrium to be established and create more favourable ion exchange conditions.

3.5.2. Effects of Adsorbent Bed Thickness

The effect of Bed thickness through removal efficiency of the adsorbent was studied; from Table 3.0, it can be observed that as the bed thickness varied from 1,2 to 3 cm, while other variables such as Flow rates and Contact time were kept constant, the removal efficiency (RE) of the adsorbent increased. This is consistent with the findings of [11] that increasing the bed thickness will increase the contact time of the adsorbate in the bed, and this will improve the removal capacity of the adsorbent.

3.5.3. Effects of Contact Time on the Removal Efficiency of the Adsorbent

Contact times of 5, 15,30, 45, and 60 minutes were used to assess the effectiveness of the adsorbent in all the trials; as contact increased, so did the removal efficiency of the adsorbent. This is consistent with the verdicts of [16] that an increase in contact time provides adequate time for the adsorption equilibrium to be established favourable for ion exchange conditions.

Table 3. Table depicts the Removal Efficiency (RE percentage) of the prepared adsorbent OGLAC-NaOH

S/No				Removal Efficiency Responses (%)						
	FR	BT	CT	Turbidity	pH	Pb	Cr	Cd	Fe	E.coli
	15	1	5	80%	10.66	13%	19%	36%	19%	74%
	15	1	15	85%	10.24	15%	22%	51%	24%	85%
1	15	1	30	95%	10.14	17%	31%	53%	29%	95%
	15	1	45	95%	10.12	21%	37%	58%	35%	95%
	15	1	60	95%	10.17	35%	48%	61%	58%	95%
	30	1	5	77%	10.88	10%	15%	32%	15%	65%
	30	1	15	91%	10.11	10%	19%	57%	22%	72%
2	30	1	30	95%	9.94	16%	25%	61%	25%	85%
	30	1	45	100%	10	17%	35%	49%	32%	85%
	30	1	60	100%	9.82	31%	47%	63%	55%	90%
	50	1	5	89%	9.97	6%	12%	34%	10%	55%
	50	1	15	89%	9.9	7%	15%	43%	22%	65%
3	50	1	30	91%	10.02	7%	20%	67%	26%	72%
	50	1	45	100%	9.78	24%	30%	71%	30%	85%
	50	1	60	100%	9.79	25%	45%	81%	58%	95%
	15	2	5	54%	11.68	42%	21%	53%	26%	100%
	15	2	15	60%	11.31	62%	39%	64%	34%	95%
4	15	2	30	85%	10.62	75%	78%	69%	56%	85%
	15	2	45	90%	10.38	75%	85%	78%	68%	72%
	15	2	60	95%	10.14	85%	95%	85%	95%	70%
	30	2	5	75%	11.18	39%	21%	47%	25%	85%
	30	2	15	82%	10.6	35%	35%	45%	32%	98%
	30	2	30	85%	10.29	42%	57%	61%	51%	100%
5	30	2	45	95%	10.05	50%	73%	65%	72%	100%
	30	2	60	95%	10.03	65%	85%	82%	82%	100%
	50	2	5	65%	10.57	32%	15%	50%	22%	72%
	50	2	15	72%	10.36	45%	30%	59%	27%	75%
6	50	2	30	85%	10.08	65%	45%	65%	33%	85%
	50	2	45	95%	10.12	71%	63%	86%	45%	90%
	50	2	60	95%	10.06	85%	95%	95%	57%	90%
	15	3	5	75%	11.44	45%	55%	66%	59%	45%
	15	3	15	84%	11.03	49%	75%	73%	75%	65%
7	15	3	30	90%	10.37	65%	85%	83%	85%	85%
	15	3	45	90%	10.65	75%	85%	85%	85%	85%
	15	3	60	95%	10.41	75%	90%	90%	90%	100%
	30	3	5	89%	11.04	23%	50%	73%	55%	55%
	30	3	15	90%	10.69	27%	72%	78%	67%	94%
8	30	3	30	95%	10.42	31%	85%	81%	80%	94%
	30	3	45	100%	10.34	39%	87%	81%	92%	98%
	30	3	60	100%	10.06	45%	92%	85%	95%	98%
	50	3	5	94%	10.87	65%	45%	75%	50%	65%
	50	3	15	94%	10.45	72%	65%	82%	62%	75%
9	50	3	30	96%	10.39	81%	79%	85%	75%	85%
	50	3	45	96%	10.41	81%	83%	90%	90%	95%
	50	3	60	100%	10.08	85%	85%	90%	100%	95%

Where FR is flow rates (ms^{-1}), BT is Bed thickness(cm) and, CT is the Contact-Time (S), % is the removal efficiency.

3.6. Results of Adsorption Optimization Studies

The final empirical model in terms of coded factors for the dependent variables (Turbidity, pH, Pb²⁺, Cr²⁺, Cd²⁺, Fe²⁺ and E. coli) was portrayed respectively in equations 2, 3, 4, 5, 6, 7, and 8. A positive sign in front of the terms indicates a synergistic effect, while a negative sign indicates an antagonist effect.

Observed removal Efficiency (Turbidity)
 = 0.9624 + 0.0401A - 0.0043B + 0.0778C + 0.0195AB - 0.0317AC - 0.0249BC - 0.0402A² + 0.0338B² - 0.0493C² (2).

Observed removal Efficiency (pH)
 = 10.28 - 0.2115A + 0.178B - 0.3491C + 0.0089AB + 0.1327AC - 0.084BC + 0.0819A² - 0.1422B² + 0.2426C² + 0.007ABC + 0.086A²B + 0.1033A²C + 0.1106AB² - 0.1374AC² + 0.199B²C - 0.006BC² 0.277C³ .(3)

Observed removal Efficiency (Pb²⁺)
 = 0.4529 - 0.0409A - 0.0869B + 0.1204C + 0.0526AB + 0.0003AC - 0.018BC + 0.2032A² - 0.2179B² - 0.0049C² - 0.016ABC + 0.1979A²B + 0.0965A²C + 0.0634AB² - 0.0013AC² - 0.109B²C - 0.0463BC² + 0.0101C³ (4).

Observed removal Efficiency (Cr²⁺)
 = 0.5931 - 0.1279A + 0.298B + 0.3226C - 0.0112AB + 0.004AC + 0.0369BC + 0.0306A² - 0.0447B² - 0.0433C² + 0.003ABC + 0.0102A²B + 0.0318A²C + 0.0357AB² + 0.0859AC² - 0.1924B²C - 0.0856BC² + 0.0472C³ .(5)

Observed removal Efficiency (Cd²⁺)

= 0.6479 + 0.0136A + 0.1338B + 0.1148C + 0.0097 AB + 0.015AC - 0.0183BC + 0.0723A² + 0.038B² - 0.0258C² - 0.0681ABC + 0.0253A²B + 0.0315A²C + 0.0376AB² - 0.0002AC² - 0.0618B²C + 0.0325BC² + 0.0689C³ (6)

Observed removal Efficiency (Fe²⁺)
 = 0.4878 - 0.1053A + 0.2851B + 0.2419C - 0.0112AB - 0.0188AC + 0.0201BC - 0.0041A² + 0.063B² + 0.0214C² + 0.0035ABC - 0.0011A²B - 0.004A²C + 0.072AB² + 0.0047AC² - 0.0722B²C - 0.0775BC² + 0.046C³. (7).

Observed removal Efficiency (E. coli)
 = 0.936 - 0.025A + 0.0757B - 0.1044C + 0.0888AB - 0.0123AC + 0.001BC - 0.0433A² - 0.0235B² - 0.0643C² - 0.0665ABC - 0.038A²B - 0.0557A²C + 0.0255AB² + 0.0235AC² + 0.2247B²C - 0.0364BC² + 0.0825C³ (8).

Where A is the Flow rate (ml/min), B is the adsorbent bed thickness (cm), and C is the contact time (mins).

Constraints for the targeted variables for OGLAC-NaOH@550 °C adsorbent are shown in Table 4.

Table 5.0. displayed the adsorption optimization solution to the optimal performance of OGLAC-NaOH as an adsorbent. The best selection was placed at number one: Flow rate of 46.39ml/min, adsorbent bed thickness 2.866 cm, and contact time of 60 mins, which will effectively remove Turbidity at (98%), pH(10.081), Pb (67%), Cr (98%), Cd(100%), Fe (92%) and E.coli (97 %).

Table 4. Constraint for the targeted variables for OGLAC-NaOH@550 °C adsorbent

Name	Goal	Lower Limit	Upper Limit	Lower Weight	Upper Weight	Importance
A	is in range	15	50	1	1	3
B	is in range	1	3	1	1	3
C	is in range	5	60	1	1	3
Turbidity	is target = 1	0.2284	1	1	1	3
pH	is target = 7.5	7.48	9.46	1	1	3
	is target = 1	0.19	1	1	1	3
Cr	is target = 1	0.27	1	1	1	3
Cd	is target = 1	0.3305	1	1	1	3
Fe	is target = 1	0.27	1	1	1	3
E.coli	is target = 1	0.31	1	1	1	3

Table 5. Displays the generated responses with the best selection

S/No.	Flow Rate (ml/min)	Bed Thickness (Cm)	Contact Time (Min)	Turbidity (%)	pH	Pb (%)	Cr (%)	Cd (%)	Fe (%)	E.coli (%)	
1	46.39	2.866	60	99	10.08	68	99	100	92	97	Selected
2	46.313	2.873	60	99	10.08	67	99	100	93	98	
3	46.618	2.845	60	98	10.07	70	99	100	92	96	
4	47.042	2.963	57.403	100	10.19	68	96	100	93	100	
5	47.387	2.948	57.103	99	10.19	70	96	100	92	99	
6	47.603	2.924	57.205	99	10.18	72	96	100	92	98	

4. Conclusion

The modification of OGL using NaOH was effective in creating well-developed pores on the surface of the precursor, thus leading to OGLAC with a large porous surface structure. These pores provided good surfaces for non-heavy, heavy metals and bacteriological contaminants to be trapped and adsorbed, also showed the presence of alcohols, Aliphatic Primary Amine, Alkane ($3850.0 - 2925.3\text{cm}^{-1}$), Thios, Carboxylic acid, Conjugated Alkene ($2351 - 1443\text{cm}^{-1}$), Aliphatic nitro compounds, Primary Amine, Aliphatic choro ($1377 - 722.27\text{cm}^{-1}$) functional groups. There was also the broadening and shortening of the adsorbents's IR peaks. The changes in FT-IR spectra confirmed the effects of carbonizing temperatures and activation on the raw OGL. Thus, higher temperature and activation play prominent roles in enhancing the functional group on the adsorbents and making possible the ability of OGL adsorbent to removal the selected traits

from the well water. The higher carbonization temperature and activation of OGL with NaOH improve its Removal Efficiency.

Furthermore, the adsorption process was highly influenced by the flow rates, adsorbent bed thickness, and contact time. The remediation patterns of the raw water impurities with the raw OGL and the adsorbent generally followed a polynomial trend. The adsorbent material achieved multi-water parameter removal but was ineffective in the remediation of the pH concentration of the adsorbate.

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