

## **Process Simulation and Experimental Validation of Wastewater Treatment from Textile Industry**

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**Abstract:** The research study investigated process simulation and experimental analysis of textile wastewater with coconut shell activated carbon as adsorbent in a continuous stirred tank reactor. Wastewater from textile industry process plant contains pollutants with concentrations above the World Health Organization standards and if discharged to the environment may cause discomfort to plants and humans due to environmental pollutions. The analysis of textile wastewater prior to treatment yielded high amount of pollutants such as chemical oxygen demand, electrical conductivity, biological oxygen demand, iron, phosphate, chloride and total hardness. Locally sourced coconut shell materials were carbonated to form activated carbon, used to treat the textile wastewater in a continuous stirred tank reactor. The adsorptions kinetics and isotherms models were studied and transient reactor model for the adsorption process was also developed to describe the process. The result indicated that pseudo-second order kinetic and Freundlich isotherm best describes the adsorption process. The adsorbent was reliable and generated good fitted data used for the model simulation process due to the pollutant concentrations were reduced below the standard set by the World Health Organization. The model results gave good predictions of the process and when compared with the experimental readings, the deviations for the pollutants ranged between 4.4% and 38.5%.

**Keywords:** Coconut shell, Textile wastewater, Adsorption, Characterization, Continuous Stirred Tank Reactor

### **1.0 Introduction**

Textile Industrial Wastewater comprises of wastewater from the municipality, sewage, rivers located around the industry, shallow wells and process water from the factories or industries located in Aba city chemical plants and Aba water board environment. This textile wastewater is

highly contaminated with pollutants majority  $\text{SO}_4^{2-}$ ,  $\text{NO}_3^-$ ,  $\text{PO}_4^{3-}$ ,  $\text{CO}_3^{2-}$ ,  $\text{HCO}_3^-$ , TSS, DO, COD, TDS and heavy metals ( $\text{Pb}^{2+}$ ,  $\text{Cu}^{2+}$ ,  $\text{Ca}^{2+}$ ,  $\text{Na}^+$ ,  $\text{Fe}^{2+}$ ,  $\text{Au}^+$ ). Thus, the ions concentration present in the water are above the standard limits set by the WHO, United Nation, and Federal Environmental Protection Agency (FEPA) Acts [1]. It is very necessary to treat the water prior discharge to its environment for domestic application such as drinking, cooking or watering etc. Gasparovic *et al.* studied integrated computational fluid dynamics (CFD) with coagulation kinetics to simulate electrocoagulation reactors for dye-laden wastewater. The authors validated the model using pilot-scale experimental data and demonstrated excellent agreement between simulated and real removal efficiencies. The CFD–kinetic coupling identified zones of poor mixing and optimized electrode arrangement, improving energy efficiency. Findings confirmed that simulation reduces trial-and-error in reactor scale-up [2]. Ayub & Khorasgani (2014) evaluated the effectiveness and usefulness of agro-waste material (coconut shells) as an adsorbent after activated to adsorbed Cr (IV) from wastewater. The removal of the ion from the wastewater was measured on factors such as pH, contact time, adsorbent dose, and concentration of metal and size of the particles. The results indicate that the adsorption of Cr (IV) obeys a first order kinetics and is endothermic with a peak adsorption of 83% at 30°C for a previous concentration of 50mg/l at pH 1.5[3]. Kulkani *et al.* (2013) formulated an adsorbent prepared from coconut shell to use for phenol adsorption from effluent water in fluidized bed reactor. The influence of factors like concentration, adsorbent particle size and fluid flow rate were investigated and results indicate that the concentration increase lead to the increased in the percent saturation of adsorption, better adsorption due to fluid flow rate increase and increase in size of adsorbent particle, decreases the percent saturation of the adsorption [4]. Oribayo *et al.* (2020) produced adsorbent from coconut shell, sourced locally used in the adsorption of dye (methylene blue) from aqueous form. Experiments conducted in batch systems were used to simulate the isotherms models (Langmuir, Freundlich and Temkin) and the adsorption kinetics and to predict the kind of isotherm and adsorption kinetics model best described the adsorption process. The adsorption process was based on the time in contact, dose of the adsorbent and concentration of the adsorbent factors [5]. Sousa *et al.* (2011) worked on base-treated green Coconut Shell Powder for the handling of Industrial Effluents (removal of toxic materials from synthetic aqueous wastes). Langmuir and Freundlich isotherms models were used to design the treatment process. Toxic metals such as  $\text{Pb}^{2+}$ ,  $\text{Ni}^{2+}$ ,  $\text{Cd}^{2+}$ ,  $\text{Zn}^{2+}$  and  $\text{Cu}^{2+}$  were all adsorbed by the base-treated green coconut shell powder [6]. Sruthi & Sheena (2019) compared

the application of activated carbon made from coconut shell and laterite in fix bed stationary phase for removal of COD and BOD from dairy wastewaters and also TSS, turbidity, pH removal too. The results indicate that BOD and COD were effectively reduced and best with coconut shell adsorbent while TSS < turbidity and pH are better removed using laterite in fixed bed stationary phase. Compared also with mixed adsorbents of ratio, 2:1 (Coconut shell activated carbon (CSAC) and laterite in fix bed stationary phase), impurities removal was high as 6 minutes only contact time, reduces BOD up to 70.16% and COD up to 52.1% from the Dairy wastewater and also pH up to 201%, turbidity up to 52.33% and TSS up to 47.53% were all reduced from the Dairy wastewater at that 6 minutes contact time [7]. Islam *et al.* applied a bibliometric and technological review mapped research patterns in textile effluent water handling from 2000 to 2022. The study found sharp growth in AOPs, membrane bioreactors, and hybrid systems. It concluded that bibliometric analysis can guide policy makers and researchers toward underexplored technologies [8]. Al-Jaberi & Siddiqui provided additional analysis of EC reactors and reactor kinetics. The review emphasized the role of CFD modeling in predicting mass transfer phenomena. The study reaffirmed the efficiency of EC but noted sustainability constraints due to sludge management [9]. Karam *et al.* reconfirmed the potential of coagulation or flocculation in textile wastewater. Key findings stressed the cost-effectiveness of combined alum-polymer systems. Practical implications included significant sludge reduction and efficient turbidity removal [10].

Therefore, proper wastewater disposal systems were created in the Roman civilization. However, the serious progress in wastewater treatment appeared only during the second half of the 19th century. As human population increases, industrialization also increased given rise to more of wastewater. It will be noticed that the untreated wastewater bodies will cause population and pose health hazards. So many studies have been done on the efficacy of foreign or imported adsorbents for wastewater treatment purposes. Also, locally sourced adsorbents have been proven to be potent in adsorbing impurities from wastewater prior to discharge to the environment. Thus, this research study will establish a process simulation and experimental validation of waste water treatment from textile industry that will be used to describe the mode of treatment of the industrial wastewater with activated carbon produced locally. The aim of the study is to analyze, treat, simulate and validate textile wastewater with coconut shells activated carbon through the production of the adsorbent, analysis of textile wastewater, its treatment and characterization to determine the pollutants present, isotherms development, kinetics and pollutant adsorption models

with coconut shell activated carbon in a continuous stirred tank reactor (CSTR) and simulates the developed models using experimental data obtained from the analysis of textile wastewater prior and after treatment.

## **2.0 Materials and Method**

### **2.1 Study Site**

Textile wastewater was collected from a garment factory at Osisoma in Abia state, Nigeria that uses raw textile materials to produce fibres or linen for clothe making. The textile wastewater taken was characterized at New Concepts Analytical and Environmental Services Limited and the coconut shell was obtained from Owerri metropolis where is present as waste product.

### **2.2 Experimental Procedures**

#### **2.2.1 Preparation of Coconut Shells**

Raw coconut shells were initially dried in the sun for over two days and then in an oven under a predetermined temperature of 65C to 100C for eight hours to dry the shells completely off all the moisture content. They were dried and then washed using tap water and then distilled water to eliminate contaminants and then dried again awaiting crushing. It was achieved by screening the finely powdered particles through a 0.18 mm mesh to achieve similar particle size. The pieces of coconut shell were finely powdered and soaked in 0.1M NaOH over a period of 9 hours and then rinsed with distilled water to eliminate all the lignin and then dried. The pieces were rinsed with distilled water and placed in 0.1M H<sub>2</sub>SO<sub>4</sub> to remove the remaining alkalinity over 9 hours after which they were thoroughly washed using distilled water. They were washed and dried again under sun and left in a desiccator until the adsorption analysis.

#### **2.2.2 Analysis of Heavy Metal**

Metal analysis was performed with the aid of Atomic Absorption Spectrophotometer (AAS). Acid digestion then filtered with a 0.45-micron membrane filter were used in the preparation of the samples. Iron (Fe) in ten aliquots of the filtrates was determined by ASTM D1068 and the lowest unit that could be detected was 0.001 mg. The sampling was done to determine the heavy metals and other ions in the ground water. The sodium ion (Na<sup>+</sup>) was specifically tested in adsorption process, unlike the other heavy metals identified [11].

The definite mass of the substance was engaged to measure the target previous concentration of Na<sup>+</sup>. To accomplish this, 2g, 5g, 10g, 15g, and 20g of the metal ion were measured and dissolved

in a certain portion of the infiltrated solution to form 10mg/l, 20mg/l, 30mg/l and 40mg/l and 50mg/l, respectively.

### 2.2.3 Adsorption Experiment

The adsorption behavior was study as analyzed thus.

#### 2.2.3.1 Effect of Adsorbent Dosage

Four stirred communication flasks that served as continuous stir tank reactors were weighed with two grams of crushed coconut shells that were treated, five grams, ten grams, fifteen grams, and twenty grams and were placed in four flasks. The textile wastewater was measured using 100 milliliters and placed in each reactor. Na<sup>+</sup> ion concentration of 10mg/L was added to the solution. The weighted activated coconut shells (adsorbent) were therefore added to each of the CSTR reactors. The PH and the average temperature in the ambience of the solutions were taken and it was observed that the PH of the initial solutions in the reactors was acidic. As a result, to obtain a uniform pH in all the reactors, the pH was standardized in each reactor using 1M NaOH to ensure that the pH across all the reactors was maintained at a constant level of 6.5. The reactor was stirred to ensure sufficient interaction between the particles and Na<sup>+</sup> in the solution. Once equilibrium conditions were reached, the mix was filtered with a filter paper to separate the solid and liquid phase. The resulting filtration was then analyzed using an Atomic Absorption Spectrophotometer (AAS) to ascertain the residual concentration of Na<sup>+</sup> ions remaining in the solution.

#### 2.2.3.2 Effect of Contact Time

The mass of adsorbent used was 20g and the initial concentration of textile wastewater was 10mg/l in the six different reactors. In each reactor, the suspension was filtered after every 30 minutes using a filter paper and the remainder, thus, was tested to determine the amount of metal ions in the solution. It was determined that the coefficient of Na<sup>+</sup> adsorbed by the coconut shell particles was as follows:

$$\text{Adsorbed Metal (\%)} = \frac{C_i - C_f}{C_i} \times 100\% \quad (1)$$

Furthermore, upon ascertaining the equilibrium amount of heavy metal ions in the liquid phase, the adsorption capacity of coconut shells at equilibrium was derived using the formula.

$$Q_e = (C_i - C_e) \frac{V}{m} \quad (2)$$

The influence of contact duration on adsorption capacity was ascertained by

$$Q_t = (C_i - C_t) \frac{V}{m} \quad (3)$$

## 2.4 Characterization of Sample

Textile wastewater sample was characterized via the application of different standardize methods prior and after treatment with coconut shell adsorbent to determine the percentage impurities and properties of the wastewater sample.

**Table 1: Parameters Characterization Techniques of Textile Wastewater**

PARAMETERS	STANDARD METHODS
Conductivity, ( $\mu\text{S}/\text{cm}$ )	Potentiometric
Dissolved Oxygen, ( $\text{mg}/\text{l}$ , $\text{O}_2$ )	Electromembrane
Biochemical Oxygen Demand, ( $\text{mg}/\text{l}$ , $\text{BOD}_5$ )	Incubation and Electromembrane
Chemical Oxygen Demand, ( $\text{mg}/\text{l}$ , COD)	Titrimetric
Turbidity, (NTU)	Nephelometric
Total Solid, ( $\text{mg}/\text{l}$ )	Gravimetric
Total Hardness, ( $\text{mg}/\text{l}$ , $\text{Ca}/\text{MgCO}_3$ )	EDTA Titrimetric
Calcium Hardness, ( $\text{mg}/\text{l}$ , $\text{CaCO}_3$ )	EDTA Titrimetric
Total chloride, ( $\text{mg}/\text{l}$ , $\text{Cl}^-$ )	Argentometric
Total Dissolved Solid, ( $\text{mg}/\text{l}$ )	Gravimetric
Total Suspended Solid, ( $\text{mg}/\text{l}$ )	EDTA Titrimetric
Phosphate, ( $\text{mg}/\text{l}$ , $\text{PO}_4^{3-}$ )	Ascorbic acid
Magnesium, ( $\text{mg}/\text{l}$ , Mg)	EDTA Titrimetric
Sodium, ( $\text{mg}/\text{l}$ , Na)	Spectrophotometric
Iron, ( $\text{mg}/\text{l}$ , Fe)	AAS
Copper, ( $\text{mg}/\text{l}$ , Cu)	AAS
Lead, ( $\text{mg}/\text{l}$ , Pb)	AAS

## 2.5 Adsorption Isotherm Models

To calculate the equilibrium behavior of the adsorption process, the trial data for the elimination of heavy metals (such as Pb, Na, Cu), as well as sulfate and chloride ions, were interpreted using the Langmuir, Freundlich, and Temkin isotherm models. These models were described how the pollutants interacted with the coconut shell-based adsorbent and to determine the mechanism governing their uptake at equilibrium.

### 2.5.1 Langmuir Isotherm

The Langmuir model marks the monolayer adsorption on specifically confined location. This implies that there is no adsorbate transmigration on the surface plane and that the monolayer sorption energies on the sorbent surface are the same [12]. The Langmuir Isotherm expression is stated as:

$$\frac{C_e}{C_{ads}} = \frac{1}{Q_b} + \frac{C_e}{Q} \quad (4)$$

Dada *et al.* expressed Langmuir isotherm model as [13]

$$q_e = \frac{Q_m k_L C_e}{1 + k_L C_e} \quad (5)$$

The linearized form of Equation 5 is described thus.

$$1/q_e = \frac{1}{Q_m k_L} \left(1/C_e\right) + \frac{1}{Q_m} \quad (6)$$

### 2.5.2 Freundlich Isotherm

Freundlich Isotherm describes the process of adsorbing on heterogeneous exteriors and active locations with diverse energy, by using multilayer adsorption and equilibrium [12, 14]. The Freundlich model of isotherm can be stated as

$$q_e = k_f C_e^{1/n} \quad n > 1 \quad (7)$$

Linearizing Equation 7 yields

$$\ln q_e = 1/n \ln c_e + \ln k_f \quad (8)$$

### 2.5.3 Tempkin Adsorption Isotherm

The Temkin adsorption isotherm incorporates an interaction parameter that accounts for adsorbate-adsorbate interactions during adsorption. It assumes that the adsorption heat of all molecules in the adsorbed layer reduces in a linear relationship with increasing surface area, rather than decreasing logarithmically at moderate concentrations [13].

The Temkin isotherm model can be expressed mathematically in the following form:

$$q_e = \frac{RT}{bT} \ln(A_T C_e) \quad (9)$$

Upon mathematical analysis yields

$$q_e = B \ln A_T + B \ln c_e \quad (10)$$

## 2.6 Adsorption Kinetics Models

The pseudo-first-order kinetic model describes the association between the rate at which adsorption sites on the adsorbent become filled and the available vacant sites remaining available for adsorption. The data indicates the rate of adsorption of heavy metals at equilibrium concentration and at a specified time [15].

$$\frac{dq}{dt} = k_1(q_e - q) \quad (11)$$

Mathematical analysis of Equation 11 yields

$$\ln(q_e - q_t) = -k_1 t + \ln q_e \quad (12)$$

The Pseudo-second-order kinetics model defined the adsorption of heavy metals from underground polluted water can be expressed as

$$\frac{dq}{dt} = k_2(q_e - q)^2 \quad (13)$$

Upon mathematical analysis and variable separation

$$\frac{1}{q_e - q_t} - \frac{1}{q_e} = k_2 t \quad (14)$$

The Elovich kinetic model is frequently used in designing chemisorption processes occurring on heterogeneous surfaces of solids and has also been extended to pollutants elimination from aqueous media [16]. It represents a second-order kinetic behavior, if the adsorbent surface possesses non-uniform energy sites and that adsorption proceeds without a clearly defined mechanistic pathway [17]. Qiu et al. characterized the Elovich Kinetic model as [18]

$$\frac{dc}{dt} = a \exp(-\varphi c) \quad (15)$$

Mathematical analysis of Equation 15 yielded a linearized equation as

$$q_t = \frac{1}{\varphi} (\ln t + \ln(\varphi a)) \quad (16)$$

The developed intra-particle diffusion kinetics model which has been effective in many cases for adsorption of heavy metals is expressed as

$$q_t = k_d \sqrt{t} \quad (17)$$

## 2.7 Transient Model Development

### 2.7.1 Model Assumptions

The assumption applied in this study include constant density reactor for adsorption process and adsorption process occurring in isothermal condition, hence no energy balance for the process.

The transient model of the CSTR is developed through the application of material balance analysis as stated thus

$$\left\{ \begin{array}{l} \text{Rate of accumulation} \\ \text{of materials within} \\ \text{the CSTR} \end{array} \right\} = \left\{ \begin{array}{l} \text{Rate of Inflow} \\ \text{of materials into} \\ \text{the CSTR} \end{array} \right\} - \left\{ \begin{array}{l} \text{Rate of outflow} \\ \text{of materials from} \\ \text{the CSTR} \end{array} \right\} - \left\{ \begin{array}{l} \text{Rate of depletion} \\ \text{of materials due to} \\ \text{adsorption process} \end{array} \right\} \quad (18)$$

Substituting into Equation 18 and mathematically analysis yielded

$$\tau \frac{dC_p}{d\tau} = C_{p0} - C_p - k_{ad} C_p^n \tau \quad (19)$$

The adsorption process follows pseudo second order kinetic parameter and Equation 19 becomes

$$\tau \frac{dC_p}{d\tau} = C_{p0} - C_p - 0.06\tau C_p^2 \quad (20)$$

### 2.7.2 Adsorption Model Simulation

The transient model equation will be simulated numerically using MATLAB inbuilt solver with the following algorithm.

$$f(C_p, \tau) = 1/\tau \{C_{p0} - C_p - k_{ad} C_p^n \tau\}$$

$$k_1 = f(\tau_0, C_{p,0})$$

$$k_2 = f(\tau_0 + h/2; C_{p0} + 1/2 k_1 h)$$

$$k_3 = f(\tau_0 + h/2; C_{p0} + 1/2 k_2 h)$$

$$k_4 = f(\tau_0 + h; C_{p0} + k_3 h)$$

$$\varphi_i = 1/6 \{k_1 + 2k_2 + 3k_3 + k_4\}$$

$$C_{p_{i+1}} = C_{p_i} + \varphi_i h$$

$$\tau_{i+1} = \tau_i + h$$

**Table 2: Adsorption Data**

Parameters	Initial Concentration	Final Concentration
	$C_{po}$	$C_p$
BOD	3.7 mg/l	2.8 mg/l
COD	48 mg/l	36 mg/l
Pb <sup>2+</sup>	0.15 mg/l	0.10 mg/l
Fe <sup>2+</sup>	0.3 mg/l	0.3 mg/l
PO <sub>4</sub> <sup>3-</sup>	142.4 mg/l	55.5 mg/l
Cl <sup>-</sup>	265.92 mg/l	245.92 mg/l
Total Hardness	92.17 mg/l	80.3 mg/l
Electrical Conductivity	382 $\mu$ S/cm	364 $\mu$ S/cm

Table 2 depicts the input parameters for the simulation of the adsorption models for the process of using coconut shells adsorbent to adsorb pollutants from textile wastewater. The initial values of the selected pollutants were obtained as a result of textile wastewater analysis in the laboratory while the final concentrations of the pollutants (BOD, COD, Fe, Pb, phosphate ions, chloride ions, total hardness, and EC) were deduced after textile wastewater treatment with adsorbent.

### 3.0 Results and Discussion

The outcomes of the experimental treatment of textile wastewater using coconut shell adsorbent were contrasted with WHO standards as shown in Table 3. Also based on the model equation developed, the model parameters simulated results were compared with experimental parameter results as highlighted in Table 3.

**Table 3: Comparison of Experimental Results**

PARAMETER	UNIT	EXPERIMENTAL	W.H.O LIMIT
Electrical Conductivity	$\mu$ S/cm	364	600
Dissolved Oxygen	mg/l	11.5	7.5
Biochemical Oxygen Demand	mg/l	3.7	30
Chemical Oxygen Demand	mg/l	72	40
Turbidity	NTU	1.378	15
Total Solid	mg/l	314	500
Total Hardness	mg/l	80.3	60

Calcium Hardness	mg/l	26.77	75
Total chloride	mg/l	245.92	1500
Total Dissolved Solid	mg/l	248.30	2000
Total Suspended Solid	mg/l	67.70	30
Phosphate	mg/l	55.00	50
Magnesium	mg/l	13.02	20
Sodium	mg/l	2.37	200
Iron	mg/l	ND	1.00
Copper	mg/l	1.77	1.00
Lead	mg/l	0.10	0.01 - 0.05

Table 3 indicates the validation outcome of the experimental process for the pollutant adsorption from textile wastewater with coconut shells activated carbon. The result shows that the pollutants concentrations are far below the standard or limit set by the World Health Organization, hence the treated wastewater could be applied for household activities and safe to be discharged to the environment.

**Table 4: Comparison of Experimental and Model Results**

PARAMETER	UNIT	EXPERIMENTAL	MODEL	DEVIATION (%)
Electrical Conductivity	μS/cm	364	223.75	38.5
Chemical Oxygen Demand	mg/l	72	49.44	31.3
Lead	mg/l	0.10	0.134	34
Iron	mg/l	ND	0.2985	-
Phosphate	mg/l	55.00	43.5	20.9
Chloride	mg/l	245.92	235	4.4
Total Hardness	mg/l	80.3	55	31.5
Biochemical Oxygen Demand	mg/l	3.7	3.5	5.4

Table 4 presented the validation results for the model and experimental analysis that showed a maximal deviation of 38.5% across the parameters, thereby showing an acceptable model prediction for the adsorption process of the pollutants concentrations from the wastewater obtained from textile industry with CSAC.

### 3.1 Adsorption Isotherms

#### 3.1.1 Langmuir Isotherm

Langmuir isotherm plot was deduced from the graph of  $1/q_e$  against  $1/C_e$  as shown in Figure 1 to determine the Langmuir constant and further factors to describe the adsorption process taking place in the CSTR for the adsorption of contaminants from textile effluent. The coconut shells adsorbent can be described as a monolayer adsorption process for the Langmuir isotherm due to its well fitted data with 78.5% coefficient of determination. Thus, this isotherm can be adopted for the research study for describing the adsorption process of the coconut shells adsorbent.

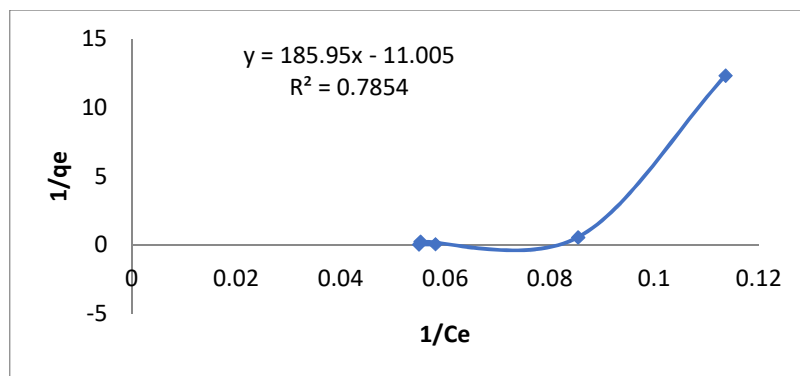


Figure 1: Langmuir Isotherm Plot

#### 3.1.2 Freundlich Isotherm

The plot of  $\ln q_e$  against  $\ln C_e$  yielded the Freundlich constant and other isotherm constants. The two-layer isotherm described by Freundlich proven more accurate with well fitted data of the adsorption process as described in Figure 2. The data obtained for Freundlich isotherm were better compared to Langmuir isotherm with 86.7% coefficient of determination.

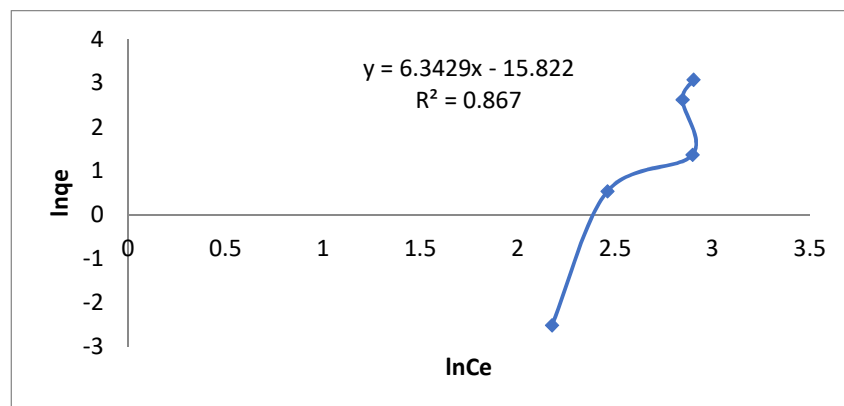
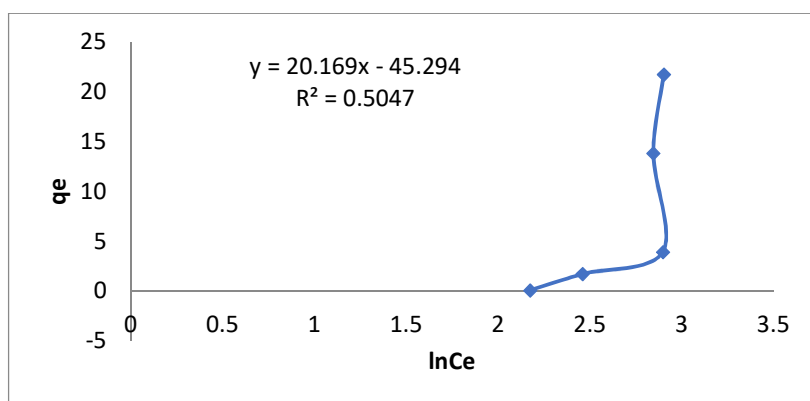


Figure 2: Freundlich Isotherm Plot

### 3.1.3 Tempkin Isotherm

Tempkin isotherm is described via the plot of  $q_e$  against  $\ln C_e$  as shown in Figure 3 with 50.47% coefficient of determination, which yielded the least isotherm values. Hence, the data fitted averagely and are not applicable for the research study.



**Figure 3: Tempkin Isotherm Plot**

### 3.2 Adsorption Kinetics

The pseudo 1<sup>st</sup> order kinetics parameter values for coconut shells adsorbent shows that the kinetic constants for the different volumes of adsorbent utilized are low due to the low  $R^2$  values (maximum of 62.6%) obtained from the adsorption of pollutants from textile wastewater in a CSTR with the coconut shells adsorbent. Also, Elovich kinetic and Intra-particle diffusion kinetic parameter values for the different volumes of adsorbent yielded very low  $R^2$  values (maximum 40.88% and 57.3%) respectively for adsorption of pollutants from textile wastewater, thus they are poorly fitted for the adsorption process. Furthermore, the pseudo 2<sup>nd</sup> order kinetic parameter (adsorption rate constant and equilibrium concentration) gave higher values with maximum 98.67%  $R^2$  value for the adsorption process of pollutants from textile wastewater in a CSTR. Thus, the pseudo 2<sup>nd</sup> order kinetic parameters are best fit for the adsorption process with good reliability.

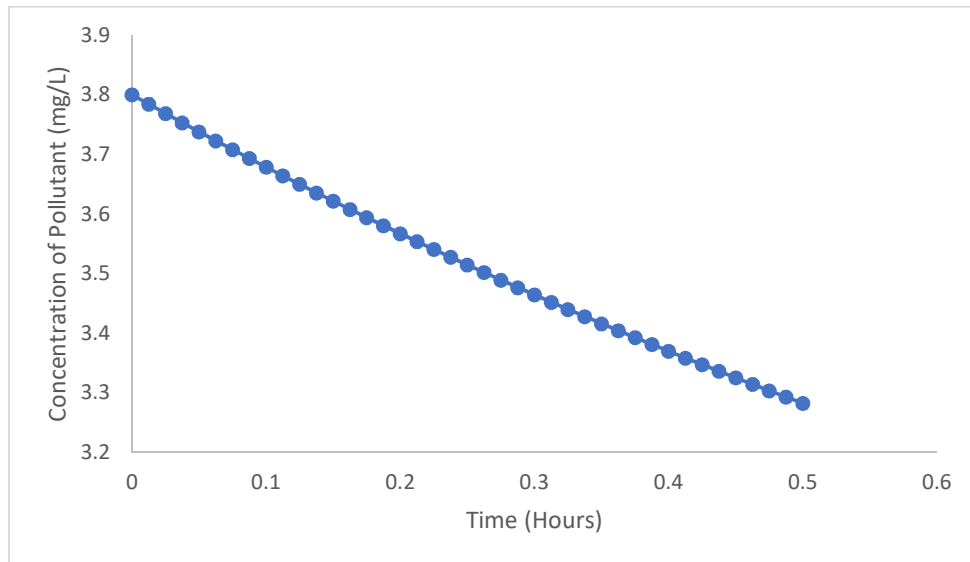
### 3.3 Adsorption Parameters Variation with Time

The variation of characterized and treated parameters of the textile wastewater with coconut shell adsorbent in a CSTR were studied with time.

#### 3.3.1 Variation of Concentration of BOD Pollutant with Time

The variation of textile wastewater BOD concentrations with time is shown in Figure 4 indicating as the adsorption process proceeds with time, there is a corresponding decline in pollutant BOD

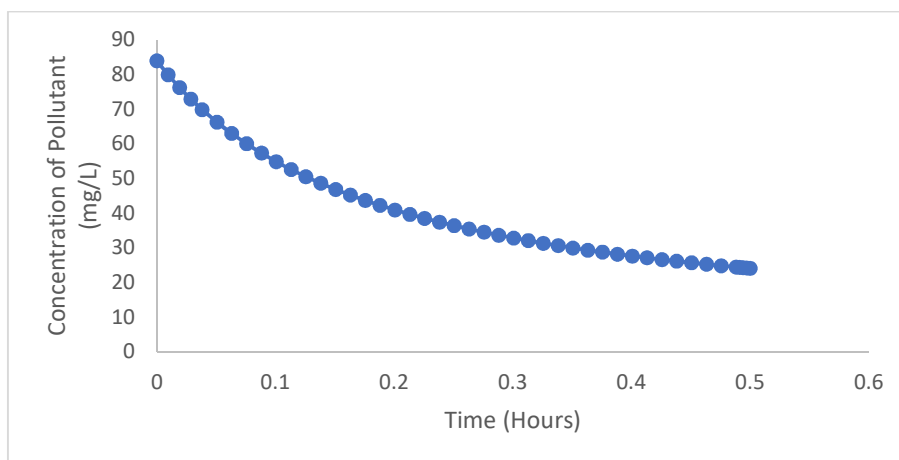
concentration. Thus, the coconut shell adsorbent continuously adsorbed the pollutant BOD as the adsorption process proceeds with time. The BOD<sub>5</sub> pollutant was adsorbed significantly from the wastewater to the barest minimum.



**Figure 4: Effect of Time on the Concentration of BOD<sub>5</sub> Pollutant**

### 3.3.2 Variation of Concentration of COD Pollutant with Time

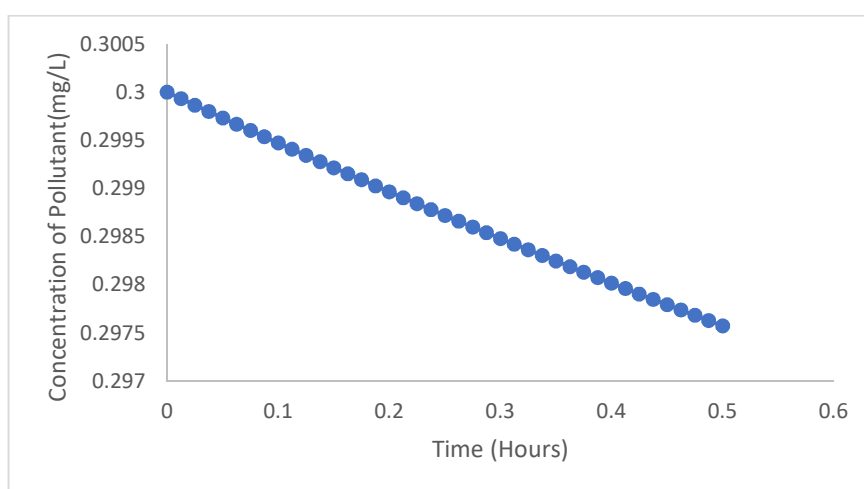
The concentration profile of COD pollutant with adsorption using coconut shells adsorbent is shown in Figure 5. The concentration of the COD pollutant decreases exponentially with time, indicating that adsorbent is efficient and able to adsorb COD particles in the textile wastewater. The result shows that the model derived using the CSTR is reliable as it well predicts the adsorption process and also the data obtained for the kinetics are good enough as the result follow the same trend.



**Figure 5: Effect of Time on the Concentration of COD Pollutant**

### 3.3.3 Effect of Time on the Concentration of Iron (Fe) Pollutant

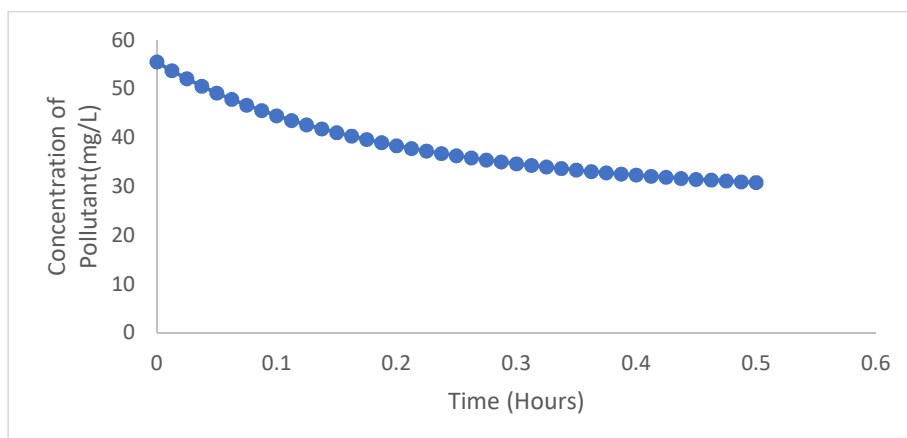
The adsorption of the concentration of Fe pollutant in the CSTR varying with time is shown in Figure 6. The concentration of Fe pollutant declines with time thereby indicating that the coconut shell adsorbent adsorbed the Fe pollutant in the wastewater and the adsorption process was continuous (CSTR) as time increases. The Fe pollutant was not completely adsorbed as slightly very small amount was adsorbed from the textile wastewater. The analysis of the textile wastewater showed low efficiency of coconut shell adsorbent in removing Fe pollutants in wastewater analysis.



**Figure 6: Effect of Time on the Concentration of Fe Pollutant**

### 3.3.4 Effect of Time on the Concentration of $\text{PO}_4^{3-}$ Pollutant

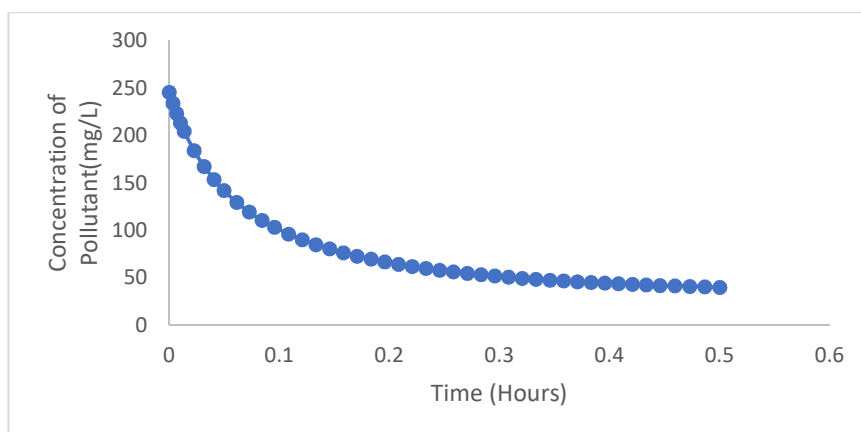
Figure 7 reveals the graph of the variation of time with concentration of  $\text{PO}_4^{3-}$  pollutant in the textile wastewater. The adsorption of the  $\text{PO}_4^{3-}$  pollutant concentration in the textile wastewater increases as time increases thereby reducing the concentration of the  $\text{PO}_4^{3-}$  pollutant exponentially in the wastewater. Thus, large amount of the  $\text{PO}_4^{3-}$  pollutant was adsorbed from the wastewater as the time increases since the concentration of  $\text{PO}_4^{3-}$  pollutant in the wastewater decreases in the presence of the adsorbent during the process. The kinetics of the adsorbent used was good for the adsorption of  $\text{PO}_4^{3-}$  pollutant, which shows that the wastewater was free from  $\text{PO}_4^{3-}$  pollutant to an extent that is below the minimum set by World Health Organization.



**Figure 7: Effect of Time on the Concentration of  $\text{PO}_4^{3-}$  Pollutant**

### 3.3.5 Effect of Time on the Concentration of $\text{Cl}^-$ Pollutant

The graph of the variation of concentration of  $\text{Cl}^-$  pollutant with time shown in Figure 8 yielded a decline in  $\text{Cl}^-$  concentration of the textile wastewater as the adsorption process of coconut shell adsorbent. The adsorption of the concentration of the  $\text{Cl}^-$  pollutant is reliable and successful with coconut shell adsorbent and the kinetics adopted for the process taken place in the CSTR. Thus, activated carbon made from coconut shells was a very good adsorbent for  $\text{Cl}^-$  pollutant and the adsorption kinetics shows that the water was completely free from  $\text{Cl}^-$  pollutant after the adsorption process was completed.

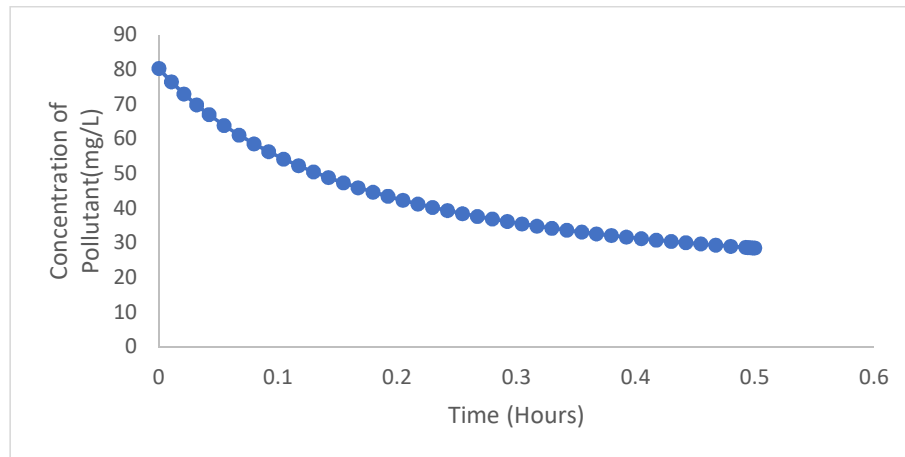


**Figure 8: Effect of Time on the Concentration of  $\text{Cl}^-$  Pollutant**

### 3.3.6 Effect of Time on the Concentration of Total Hardness Pollutant

The graph of the variation of concentration of total hardness pollutant with time decreases exponentially as shown in Figure 9. The result of the treated wastewater shows that the adsorbent is highly effective as it nearly adsorbed all the total hardness pollutant from the wastewater during

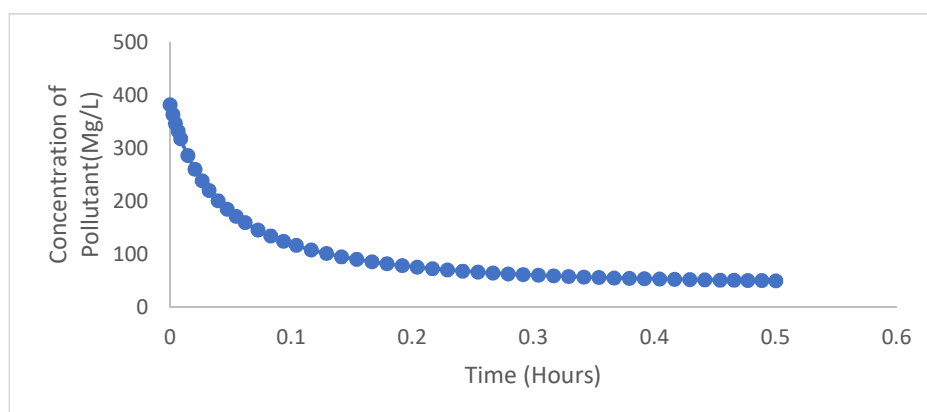
the adsorption process. This showed that coconut shells was a very good adsorbent for total hardness pollutant and the adsorption kinetics of the adsorption procedure was good for the adsorption. The kinetics shows that the water was completely free from total hardness pollutant after the adsorption process was completed.



**Figure 9: Effect of the Time on the Concentration of Total Hardness Pollutant**

### 3.3.7 Effect of Time on the Concentration of EC Pollutant

The variation of concentration of electrical conductivity (EC) pollutant in the textile wastewater with time is highlighted in Figure 10. The adsorption of the EC pollutant concentration in the textile wastewater increases as time increases thereby reducing the concentration of the EC pollutant in the textile wastewater. Thus, the coconut shell activated carbon adsorbent adsorbed large amount of EC pollutant in the treatment of the textile wastewater thereby confirming its efficacy as an adsorbent. Also, the adsorption kinetics shows that the textile wastewater was free from EC pollutant in accordance with World Health Organization.



**Figure 10: Effect of the Concentration of EC Pollutant varying with Time**

#### 4.0 Conclusion

The activated carbon produced from the coconut shells were applied as adsorbent in the CSTR reactor for the adsorption or treatment of impurities from textile effluents and the results achieved are in tandem with other studies of Pooja, Dutta *et al.* and Kato & Kansha respectively [19-21]. The research study was able to identify clearly, which of the pollutants were adsorbed and best suitable for the adsorption process of CSAC adsorbent. BOD, COD, total hardness, chloride ions, Fe, and EC were removed by the adsorbent as with good coefficient of determination,  $R^2$  values. The adsorption isotherms and kinetics processes were studied to determine which isotherm and kinetics were suitable for the process under study. Langmuir and Freundlich isotherms gave a good coefficient of determination of over 70% with well fitted data while pseudo second order kinetics yielded best result for the kinetic modeling. The transient model equation was developed and simulated to give a transient behaviour of the adsorption process at isothermal condition. Thus, further research can be carried out in this area of CASC study by considering the life cycle of the produced CASC adsorbent, the techno-economic analysis of the adsorbent with reference to other available adsorbent for treating wastewater and adsorbent regenerator based on its commercial application.

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### Nomenclature

$v_1$  =  $\text{AgNO}_3$  that will be used in titration

$v_2$  = Volume of  $\text{AgNO}_3$  that was used for titration of blank.

$Q_e$  = Capacity for adsorption, at equilibrium (mg/g)

$Q_t$  = Capacity for Adsorption, at time t (mg/g)

$C_f$  = Metal ion final amount of in the liquid mix (mg/l)

$C_i$  = Metal ion previous amount in the liquid mix (mg/l)

$C_o$  = Metal ion amount in the liquid mix, equilibrium (mg/l)

V = Liquid volume (ml)

m = Adsorbent mass(g)

$C_{\text{ads}}$  = Adsorbed concentration of heavy metal and other ions at equilibrium.

$Q_b$  = Sorption constant (mg/l) at temperature t, connected to sorption energy,

$Q$  = Highest sorption capacity (mg/g)

$C_e$  = Equilibrium constant (mg/L)

$Q_m$  = Highest monolayer coverage capacity (mg/g)

$k_L$  = Langmuir Isotherm constant (l/mg)

$k_f$  = Freundlich Isotherm constant

$n$  = Intensity of adsorption

$q_e$  = Adsorbate equilibrium amount (mg/l)

$C_e$  = Amount of heavy metal and other ions adsorbed at equilibrium

$A_T$  = Tempkin Isotherm equilibrium binding constant (l/g)

$b_T$  = Tempkin Isotherm constant

$R_T$  = Universal gas constant (8.314 J/mol. K),

T = Temperature (298K)

B = Heat of sorption constant (J/mol).

$q_e$  = Adsorbed amounts of heavy metal by the adsorbent, equilibrium (mg/g)

$q_t$  = Adsorbed amounts of heavy metal by the adsorbent, at time  $t$  (mg/g)

$k_1$  = Rate constant of absorption ( $\text{hr}^{-1}$ )

$k_2$  = Pseudo-second-order rate constant (g/mg.hr)

$t$  = Measured time of adsorption (hr)

$a$  = Adsorption constant

$\varphi$  = Initial adsorption rate (mg/g hr)

$q_t$  = Amount of heavy metal absorbed at time (mg/g)

$k_d$  = Rate constant for Weber and Morris intra-particle diffusion (mg/g.hr<sup>0.5</sup>)

$t$  = Adsorption time of (hr)

$(-r_i)$  = Rate expression due to adsorption process is dependent on the adsorption kinetics (either Pseudo first, second, Elovic or intra particle kinetics known);

$k_{ad}$  = Adsorption rate constant

$C_{po}$  = Initial pollutant concentrations

$C_p$  = Concentration of pollutants, (mol/m<sup>3</sup>)

V = Volume of the reactor, m<sup>3</sup>

$v_o$  = Volumetric flow rate adopted constant via out the reaction process, m<sup>3</sup>/s

$\tau$  = Space time of the adsorption process occurring in CSTR

h = Step size chosen for the iteration processes