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Experimental Validation of Textile Industrial Waste Water Treatment

Eke Lovegod Anthony[1], Unwana Iniobong Udoumoh[2], Ekine Onengiyeofori Hamilton[1], Emmanuel-Nathaniel, Obinna Pearson[1]

[1]Department of Chemical/Petrochemical Engineering, Rivers State University, Nkpolu-Oroworukwo, Port Harcourt, Nigeria

[2]Department of Civil and Water Resources Engineering, University of Delta, Agbor, Delta State, Nigeria

ABSTRACT: The research focused on the experimental validation of industrial textile wastewater treatment via its treatment with activated coconut shells as an adsorbent. Wastewater from textile industry process plant contains toxic substances or pollutants with concentrations above World Health Organisation standards and if discharged to the environment may cause discomfort to plants and humans due to environmental pollutions. The characterization of industrial textile wastewater prior and after experimental process using activated coconut shell adsorbent were studied in this research with sulphate ion, nitrate ion, phosphate ion, carbonate ion, total suspended solids, dissolved oxygen, chemical oxygen demand, total dissolved solids and heavy metals were identified. Locally sourced coconut shell materials were carbonated to form activated carbon and was applied for the treatment of the industrial textile wastewater with the characterization results fell within acceptable standard f the Worl Health Organisation. The adsorption isotherm (Lagmuir, Freundlch and Tempkin) models were studied for this research with Freundlich isotherm model best describes the adsorption process with coefficient of determination (R^2) value of 86.70%. Also, parametric effects on the concentration of pollutants in the industrial textile wastewater were studied with experimemtal time to ascertain the activity of the activated coconut shell in treating he industrial textile wastewater.

KEYWORDS: Wastewater, Characterization, Adsorbent, Adsorption isotherm, pollutant.

1.0 INTRODUCTION

Industrial waste from different sources that includes refineries, petrochemical plants, and paint industries etc are evacuated into into aquatic systems. These leads to various health, flora and fauna challenges, hence, safe evacuation of such wastewater into land or aquatic systems is an important challenging task before the engineer (Prashant *et al.*, 2012). Both microbiological and chemical pollutants of drinking water are included in the WHO Guidelines for Drinking-water quality, which also provide a detailed description of the scientific methods used to determine the recommended levels for these contaminants. (WHO, 2006). Textile Industrial Wastewater comprises of wastewater from the municipality, sewage, the rivers located around the industry, shallow wells and process water from the factories or industries. The textile wastewater is highly contaminated with pollutants mainly sulphate ion (SO_4^{2-}), nitrate ion (NO_3^-), phosphate ion (PO_4^{3-}), carbonate ion (CO_3^{2-}), hydrogen-carbonate ion (HCO_3^-), total suspended solids (TSS), dissolved oxygen (DO), chemical oxygen demand (COD), total dissolved solids (TDS) and heavy metals such as lead ion ((Pb^{2+}), copper ion (Cu^{2+}), calcium ion (Ca^{2+}), sodium ion (Na^+), iron II ion (Fe^{2+}), gold ion (Au^+) etc and due these ions, textile wastewater concentration are above the accepted standard limits by WHO, UN, and Federal Environmental Protection Agency (FEPA) Acts. It is very important to treat the waters before releasing for domestic application, since these waters are sent to the communities around and are consumed either for drinking, cooking or watering etc. The water become wastewater when there are pollutants after analysis and the pollutants concentrations are high above standard sets by W.H.O, UN and FEPA (Adeloye *et al.,* 2026). The toxic and hazardous characteristics of wastewater have been widely documented (Metcalf & Eddy, 2004; *Okoya et al.*, 2020). The textile wastewater treatment is the removal of these undesired impurities and the restoration of natural water quality (Sousa, 2011) prior to its discharge to the surrounding. As solid items decays, it makes use of oxygen, and this is necessary for survival of the plants and animals in the water. Ayub and Khorasgani (2014) evaluated the effectiveness and usefulness of agro-waste material as an adsorbent after activated to adsorbed Cr (IV) from wastewater. The removal of the ion from the wastewater was analysed via pH, contact time, adsorbent dose, and concentration of metal and particle size. Kulkani *et al*. (2013) formulated an adsorbent prepared from coconut shell to use for the adsorption of phenol from wastewater in fluidized bed reactor. Oribayo *et al*. (2020) produced adsorbent from coconut shell, sourced locally used in the adsorption of dye (methylene blue) from aqueous solution. 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 practice of wastewater disposal can be traced back to ancient Roman civilization, where early systems were designed primarily for sanitation and drainage. However, significant advancements in wastewater treatment only began to emerge in the latter part of the 19th century. With the rapid growth of human populations and industrial activities, the volume of wastewater generated has increased substantially. If left untreated, such wastewater can contaminate natural water bodies, leading to severe environmental degradation and posing serious public health risks (Adeloye *et al.,* 2026). Several research has been done to produce adsorbents sourced locally to treat and predict the level of pollutants concentrations present in the wastewater polluted environment. Hence, the aim of this research is the removal of impurities or poisonous constituents from industrial textile waste water via activated coconut shell and its validation prior to its discharge to the environmental. This will be achieved through the production of an adsorbent from coconut shells, analysis and characterization of industrial textile wastewater, its treatment with activated coconut shell and analysis of adsorption isotherm models that best described the overall operational process.

2.0 METHODS

2.1 Sample Preparations

The collected textile wastewater and coconut shell was obtained from igwuruta community in Rivers State prior to its transportation to the laboratory and subjected to analysis, concentration (removal of impurities and dirts) and characterization.

2.2 Preparation of Coconut Shells

The concentration and preparation of raw coconut shell applied in this research as adsorbent for the treatment and removal of impurities from textile waste water before its discharge to the environment follows the preparatory principle applied by Adeloye *et al.,* 2026 in their research. This involved initially sun drying of raw coconut shell for some days and then oven dried to a predetermined temperature of 65^0C to 100^0C for 8 hours to remove moisture content from the coconut shell completely. After the coconut shell concentration, it was dried again and crushed into fine powdered particles using a crusher and screened into fine powdered particles using 0.18 mm mesh size to obtain similar particle size. The finely powdered coconut shell was soaked in 0.1M NaOH over a period of 9 hours and then rinsed with distilled water to remove present lignin and then dried. The resulting constituent was rinsed again with distilled water and placed in 0.1M H_2SO_4 to remove the remaining alkalinity over 9 hours after which they were rinsed thoroughly washed using distilled water and dried again under sun and stored in a desiccator to prevent moisture absorption prior to adsorption analysis

2.3 Characterization of Textile Wastewater

2.3.1 pH (Hydrogen Ion Concentration)

The pH of the wastewater samples was determined using a pH meter. A small volume of the sample was poured into a clean beaker and mixed thoroughly. The pH electrode was then immersed in the sample, and the reading was displayed directly on the meter and recorded. Prior to measurement, the pH meter was standardized using a buffer solution to ensure accuracy.

2.3.2 Dissolved Oxygen—ASTM D888A

The dissolved oxygen (DO) concentration was measured following the Winkler titrimetric method. Samples were first fixed by adding a divalent manganese solution and a strong alkaline reagent to precipitate manganese hydroxide and prevent biological activity. The samples were then acidified and titrated with standard sodiumthiosulphate solution using starch indicator to detect the endpoint.

2.3.3 Chloride Ion

Chloride ion concentration was determined by silver nitrate ($AgNO_3$) titration. A 100 ml aliquot of the sample was transferred into a 250 ml Erlenmeyer flask, followed by the addition of 0.5 ml potassium chromate (K_2CrO_4) as an indicator, which imparted a yellow colour. Standard $AgNO_3$ solution was added dropwise from a burette until a brick-red color appeared, indicating the endpoint.

2.3.4 Nitrate

To determine nitrate concentration, 2 ml of H_2SO_4 and 0.2 ml of brine were added to 2 ml of the water sample. The mixture was heated in a boiling water bath (≈98°C) for 25 minutes, cooled, and analyzed using a Spectronic 21 spectrophotometer at 410 nm. The nitrate concentration was therefore evaluated

2.3.5 Ammonia

Ammonia-nitrogen concentration was determined by adding and mixing thoroughly 5 ml of the sample, 0.2 ml of phenol solution and 0.2 ml of sodium nitroprusside respectively. 0.5 ml of an oxidizing reagent was then added, and the mixture was left to stand before measuring absorbance at 630 nm using a spectrophotometer, and the concentration was computed

2.3.6 Sulphate

Sulphate concentration was analyzed using the gravimetric method. 20 ml of the sample was transferred into a 50 ml Erlenmeyer flask, and 1 ml of conditioning reagent was added. Barium chloride ($BaCl_2$) crystals were introduced to form a turbid suspension, which was then measured spectrophotometrically at 420 nm.

2.3.7 Total Dissolved Solid

Total Dissolved Solid was determined using a conductivity bridge (Lovibond NS Meter, Type CM-21). The meter's electrode was first standardized with distilled water, after which it was immersed in the wastewater sample. Once the reading stabilized, the Total Dissolved Solid value was displayed and recorded.

2.3.8 Heavy Metals

Analysis of heavy metals in the wastewater samples was carried out using an Atomic Absorption Spectrophotometer (AAS) following ASTM standard procedures. Prior to analysis, the samples were subjected to acid digestion to break down organic matter and release bound metal ions. The digested samples were then filtered through a 0.45 µm membrane filter to remove suspended particles and other impurities. Using the filtrates, ten (10) aliquots were analyzed for Iron (Fe) in accordance with ASTM D1068. The minimum detectable concentration for the analysis was 0.001 mg/L. The AAS was used not only to quantify metal concentrations in the wastewater sample, but also to assess the physicochemical properties of the adsorbents. The purpose of the analysis was to identify the types and concentrations of heavy metals present in the wastewater, as well as other associated ions. Therefore, in preparation of the desired initial concentrations of sodium ions, accurately weighed quantities of the metal salt were dissolved in measured volumes of the contaminated solution. Specifically, 2 g, 5 g, 10 g, 15 g, and 20 g of the sodium compound were each weighed and diluted to obtain corresponding concentrations of 10 mg/L, 20 mg/L, 30 mg/L, 40 mg/L, and 50 mg/L, respectively. These solutions were then used in subsequent adsorption experiments to evaluate the performance of coconut shell in removing sodium ions from contaminated water.

2.4 Adsorption Isotherm Models

The adsorption isotherm for the adsorptive removal of heavy metals (Pb, Na, Cu) etc and sulphates and chloride ions by coconut shells were examined using the Langmuir, Freundlich, and Tempkin Isotherm models. Data were fitted to the isotherm models to deduce the best isotherm model that describe this research operational process.

2.4.1 Langmuir Isotherm

The Langmuir isotherm model explains monolayer adsorption occurring on specific, localized adsorption sites of a sorbent surface. It assumes that all adsorption sites possess uniform energy levels and that each site can hold only one adsorbate molecule, and that there is no lateral movement or interaction of adsorbed molecules across the surface. Dada *et al.*, 2012 and Adeloye *et al.*, 2026 expressed Langmuir isotherm model as:

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

Linearization of Equation 5 yields

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

Hence, a plot of $1/q_e$ vs $1/C_e$ yielded a straight-line graph with the value of Q_m and k_L determined from intercept and slope respectively.

2.4.2 Freundlich Isotherm

Freundlich isotherm model describes adsorption routes occurring on heterogeneous locations that possess active sites with varying energy levels. It is an empirical model that assumes multilayer adsorption and establishes a variation between the concentration of adsorbate in the solution and its equilibrium adsorption on the surface. The linearized Freundlich isotherm model yields

$$\ln q_e = 1/n \ln c_e + \ln k_f \qquad (7)$$

Plotting $\ln q_e$ versus $\ln c_e$ yielded a straight-line graph with n and k_f evaluated via the slope and intercept respectively

2.4.3 Tempkin Isotherm

Tempkin isotherm model accounts for adsorbate–adsorbate interactions during the adsorption operation by assuming that there is a linear decline in adsorption heat for all molecules in the layer as surface coverage increases, rather than a logarithmic trend. Furthermore, the model suggests that the binding energies of adsorption sites are uniformly distributed up to a certain maximum energy level. The Tempkin isotherm model is expressed as:

$$q_e = \frac{RT}{b_T}\ln A_T + \frac{RT}{b_T}\ln c_e \qquad (8)$$

3.0 RESULTS AND DISCUSSION

3.1 Characterization Analysis

The results of the experimental treatment of textile wastewater using coconut shell adsorbent were compared with World Health Organisation standards as depicted in Table 1. It can be posited from Table 1 that the concentrations of pollutants or impurities after wastewater treatment with activated coconut shell falls below the limit or standard set by the World Health Organization. Thus, the treated textile wastewater is safe for environmental discharge and household applications. Table 1 shows the result of the experimental analysis for the adsorption of pollutants from textile wastewater with activated coconut shells and the World Health Organization standard. The result showed that the pollutants concentrations are within or below the World Health Organization standard or limit. Therefore, it can be concluded or posited that the treated textile wastewater is applicable for domestic use and safe environmental discharged.

3.2 Langmuir Isotherm Model Analysis

Langmuir isotherm model showed in Figure 1 was applied to evaluate the Langmuir constant and other parameters. The coconut shells applied to produce the activated carbon for the adsorption process can be described as a monolayer adsorption operation for the Langmuir isotherm since the data were well fitted with the coefficient of determination (R^2) value as 78.54%. This shows that Langmuir isotherm model can be adopted for this research as it described the adsorption process of the coconut shells adsorbent.

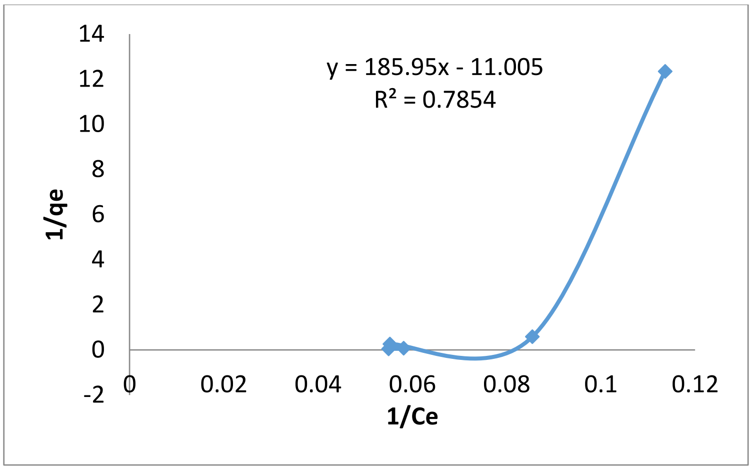

Figure 1: Plot 1/qe versus 1/Ce

Table 1: Characterization Results of Treated Textile Wastewater with W.H.O Standards

Sn	Properties	Characterization Results	WHO Standard
1	Electrical Conductivity (µS/cm)	361	600
2	Dissolved Oxygen (mg/l)	10.2	7.5
3	Biochemical Oxygen Demand (mg/l)	3.5	30
4	Chemical Oxygen Demand (mg/l)	68	40
5	Turbidity (NTU)	1.235	15
6	Total Solid (mg/l)	322	500
7	Total Hardness (mg/l)	78.2	60
8	Calcium Hardness (mg/l)	22.65	75
9	Total chloride (mg/l)	210.85	1500
10	Total Dissolved Solid (mg/l)	215.40	2000
11	Total Suspended Solid (mg/l)	56.70	30
12	Phosphate (mg/l)	46.00	5.0
13	Magnesium (mg/l)	15.20	20
14	Sodium (mg/l)	2.20	200
15	Iron (mg/l)	ND	1.00
16	Copper (mg/l)	1.56	1.00
17	Lead (mg/l)	0.015	0.01 - 0.05

3.3 Freundlich Isotherm Model Analysis

The plot of $\ln q_e$ against $\ln C_e$ describes the Freundlich isotherm model in which the model parameters can be determined via Figure 2. The two-layer isotherm described by Freundlich model proved efficient and fitted well, and the data collected aligned reasonably for the adsorption of the pollutants from textile wastewater. Thus, the obtained data for Freundlich isotherm model were compared to Langmuir isotherm model data since the coefficient of determination for the Freundlich isotherm model is 86.70%, which is higher than Langmuir isotherm model value.

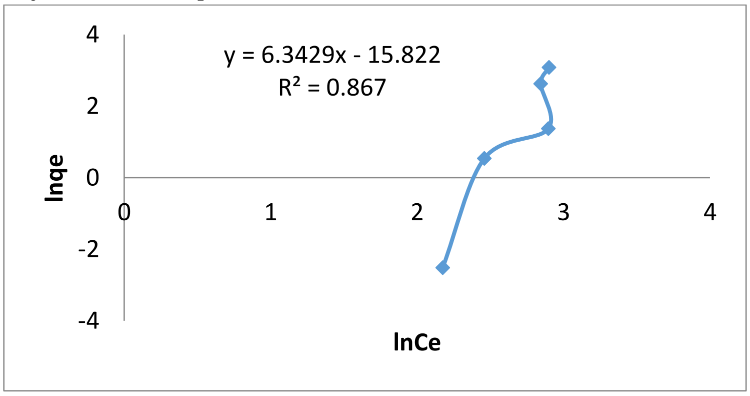

Figure 2: Plot of $\ln q_e$ versus $\ln C_e$

3.4 Tempkin Isotherm Model Analysis

Tempkin isotherm model is analysed from the plot of q_e against $\ln C_e$ as depicted in Figure 3. Though the coefficient of determination (R^2) value for the Tempkin isotherm model gave 50.5%, which is the least value of the coefficient of determination (R^2) value among the isotherm models. It thus describes the activated coconut shells adsorption operational process but with minimum accuracy since the data fitted averagely and hence are not précised for this research.

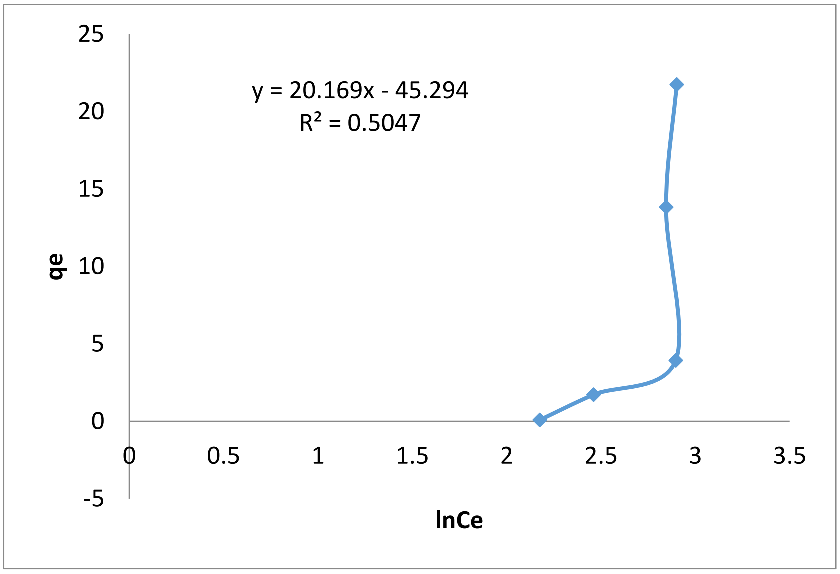

Figure 3: Plot of q_e versus $\ln C_e$

Furthermore, Table 2 highlights the isotherm constants and parameters for the Langmuir, Freundlich, and Tempkin isotherms models developed respectively, which described the adsorption process of the pollutants from textile wastewater using activated coconut shells adsorbent. The Freundlich isotherm best described the adsorption process and it is best fitted for this research due to the coefficient of determination (R^2) value of 86.7% > 78.5% > 50.5%, though the three isotherm models describes the adsorption process because of R^2 values are above 50%.

Table 2: Adsorption Isotherm Parameters obtained from the Adsorption Process

Activated Coconut shells Adsorbent		
1.	Longmuir	Value
	Qm (mg/g)	-0.090
	k_L (l/mg)	-0.0592
	R^2	0.7854
2.	Freundlich	
	n (-)	0.158
	k_f (-)	1.345×10^{-7}
	R^2	0.867
3.	Tempkin	
	B (J/mol)	20.169
	A_T(l/g)	0.106
	b_T (-)	124.902
	R^2	0.505

3.5 Parametric Effects on Concentration of Total Hardness Pollutant

The adsorption of the concentration of total hardness pollutant with time using activated coconut shells shown in Figure 4.

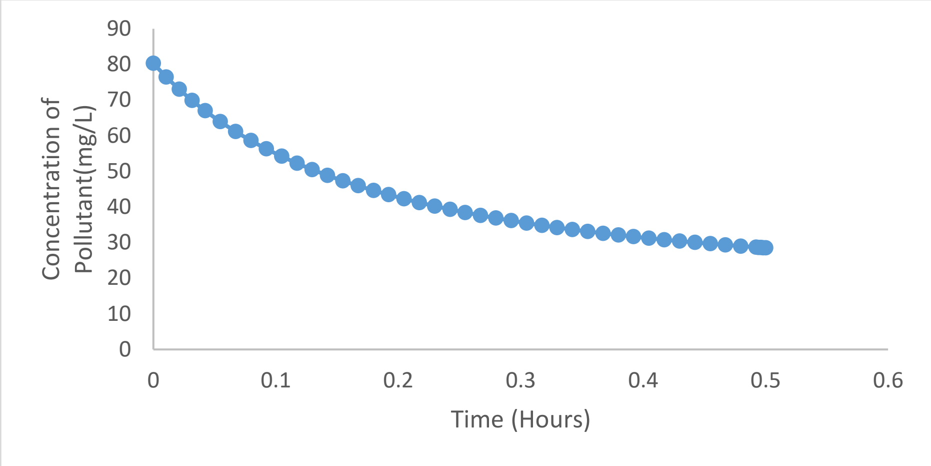

Figure 4: Effect of Concentration of Total Hardness Pollutant with Time

The graph of the variation of concentration of total hardness pollutant with time decreases exponentially from 80mg/L to 28.5mg/L as the adsorption operational time increases during the adsorption process with activated coconut shells adsorbent. In comparison with the textile wastewater analyzed, the result of the treated textile wastewater showed that the activated coconut shell adsorbent is highly effective as it nearly adsorbed all the total hardness pollutant from the wastewater as the time increases during the adsorption process. Thus, activated coconut shells is a very good adsorbent for total hardness pollutant removal.

3.6 Parametric Effects of Concentration of Electrical Conductivity Pollutant

Figure 5 indicates the plot of the variation of concentration of Electrical conductivity pollutant with time.

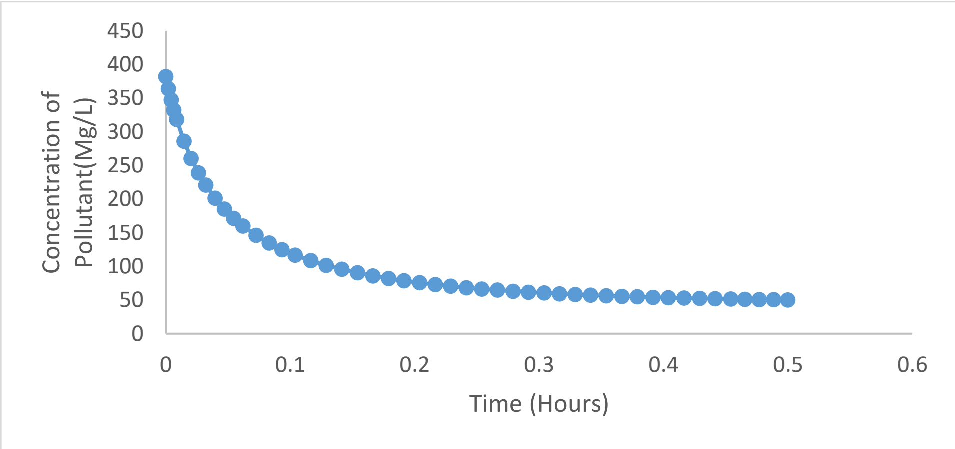

Figure 5: Effect of Concentration of EC Pollutant with Time

The adsorption of the EC pollutant concentration in the textile wastewater increases as time increases thereby reducing the concentration of the EC pollutant exponentially in the wastewater at increasing time. Thus, the adsorption process via activated coconut shell adsorbent was able to adsorb the EC pollutant during the treatment of the textile wastewater and the adsorption process was continuous as the time increases. Hence, large amount of the EC pollutant was completely adsorbed from the textile wastewater as the time increases since the concentration of EC pollutant in the wastewater decreases and the textile wastewater was free from EC pollutant to an extent below the minimum set by the World Health Organisation.

4.0 CONCLUSION

Coconut shells are sourced locally and available raw material activated to produced adsorbent applied for the adsorption of impurities from textile effluent wastewater. The research was able to clearly identify the adsorbed pollutants and best suitable for the adsorption process. BOD, COD, total hardness, chloride ions, Fe, and EC were removed by the adsorbent and the experimental characterization results yielded values within or below the acceptable World Health Organisation data. The adsorption isotherms were studied at different volumes of the adsorbent applied to describe the mono or multilayer isotherms models developed that best fitted and described activated coconut shell adsorbent process isotherm profile. The coefficient of determination (R^2) value of 86.70% was achieved by Freundlich isotherm model and was the best adsorption isotherm for the adsorption of pollutants from industrial textile wastewater using activatd coconut shells.

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Nomenclature

C_e = Equilibrium constant *(mg/L)*

Q_m = Maximum monolayer coverage capacity *(mg/g)*

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

k_f = Freundlich Isotherm constant

n = Adsorption intensity

q_e = Equilibrium concentration of adsorbate *(mg/l)*

C_e = amount of heavy metal and other ions adsorbed at equilibrium

A_T = Temkin Isotherm equilibrium binding constant *(l/g)*

b_T = Tempkin Isotherm constant, R_T = universal gas constant (8.314 *J/mol. K*),

T = Temperature at 298K