

Utilization of Sawdust (*Gossweilerodendron balsamiferum*) as an Adsorbent for the Removal of Total Dissolved Solid Particles from Wastewater

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Abstract– In this paper, the effectiveness of granular activated carbon made from agricultural waste (sawdust) for the removal of Total Dissolved Solid Particles (TDSP) in wastewater from a brewery industry was investigated. The adsorbent activation capacity was enhanced by treating it with acid. Batch mode experiments were conducted to study the effects of contact time, pH, temperature, and adsorbent dosages on TDSP adsorption. Equilibrium adsorption isotherms, kinetics and sorption mechanism were investigated from the results generated from batch experiment. The experimental data were analyzed by Langmuir, Freundlich, and Temkin models and the isotherm data fitted well to the Langmuir isotherm, with monolayer adsorption capacity of 8.40mg/g. The kinetic data obtained at different dosages were analyzed using Pseudo-first order, Pseudo-second order and the sorption mechanism was also analyzed using Intraparticle diffusion model. The experimental data fitted very well the Pseudo-second order kinetic model. The intraparticle diffusion analysis obtained shows the adsorption process as one of the rate determining steps. The sawdust activated carbon in acid (SACA) was found to be effective and economically viable adsorbent for TDSP adsorption.

Keywords– Adsorption, FTIR, Kinetics, Thermodynamic, Isotherms and Sawdust

I. INTRODUCTION

Health and environmental issues derived from waste effluents are universally admitted problems. The usually complex compositions of wastewater lead to intricate treatment processes with accordingly high costs, which are impractical given the large volumes of waste produced both domestic use and industrial use. These industries discharge wastewaters which carry high concentration of dissolved solid particles and suspended solid particles. These wastewaters should be treated for safe disposals which meets the regulations imposed on industrial sectors. The Industrial wastewater which contains high concentration of Total Dissolved Solid Particles (TDSP), has been a difficult task in removing [1]. TDSP values in wastewater can exceed 100000mg/l [2].

Many industrial activities consume large amounts of water and some of them, particularly the brewery, textile, paper, plastics, coal, food, paint, tanning, petrochemical, pharmaceutical and dye industries, discharge effluents containing TDSP, various chemicals and organic pollutants,

most of which are toxic to humans and harmful to the environment [2]–[7].

Brewery waste water is the combination of wastewater from various stages of production; malting, milling, wort boiling, stabilization, maturation, fermentation and clarification. Brewery process uses large amount of water in which malting, milling and clarification uses most of the water. Considering the volume generated and the effluent composition, the brewery industry wastewater is rated as one of the most polluting among all industrial sectors [8]. As a result, the removal of TDSP from brewery effluent has become environmentally important. Biological treatment and nutrient removal methods were reported to both decrease the TDSP contents of wastewater. Neither process however, completely removes all dissolved organic constituents, nor does neither process remove significant amounts of inorganic dissolved solids. Therefore further treatment will be required where substantial reduction in the total dissolved solid of wastewater must be made. Ion exchange, micro porous membrane, filtration, adsorption, coagulation/flocculation and chemical oxidation can be used to decrease the TDSP content of wastewater [9].

Among these several chemical and physical methods, the adsorption onto activated carbon has been found to be superior to other methods for removal of TDSP from wastewater solution in terms of its capability for efficient adsorption of a broad range of various adsorbate, low cost, availability and its simplicity of design [10]. Commercially available activated carbons are still considered as expensive materials for many countries due to the use of non-renewable and relatively expensive raw materials such as wood and coal [11]. Therefore, in recent years, this has prompted a growing research interest in the production of activated carbons from renewable and cheaper precursors which are mainly industrial and agricultural wastes. These materials are locally available in abundance and are interesting both economically and environmentally because they can be obtained easily and include such renewable raw materials as cotton stalks [12], Coconut (*Cocos nucifera*) bunch waste [13], coconut shells [14], oil palm (*Elaeis*) fruit bunch [15], bamboo [16], coffee grounds [17], Pineapple stem [18] and *Hevea brasiliensis* Sawdust [19].

Activated carbons are some of the most widespread agents for the treatment and purification of water. Their high

porosities, from macro to micro porous structures, make them efficient adsorbents to trap low molecular weight chemicals such as metal ions, dyes and other organic compounds. This is achieved through adsorption processes, where the atoms and molecules are fixed to the carbon surface via physical interactions or chemical bonds. Activated carbons are produced by treating organic precursors at high temperatures. This removes volatile components such as water and biomass, leaving void spaces which form the characteristic porous structure [20]. The activation of such raw materials produces a porous structure within these materials, which allows for remarkable adsorption capacities.

In this work, we attempt to use *Gossweilerodendron balsamiferum* Sawdust, an agricultural waste abundantly available in Nigeria as an adsorbent to remove TDSP from brewery wastewater and to evaluate the equilibrium isotherms, kinetics, and sorption mechanism for TDSP adsorption onto SACA.

II. MATERIALS AND METHOD

A) Preparation of Adsorbent

Sawdust used for the preparation of the activated carbon was obtained from the timber workshop in Enugu, Nigeria. The ligno cellulose material (sawdust) was first washed to remove dirt from its surface and then dried overnight in an oven at 110°C. The dried samples were easily crushed into small pieces and sieved to the size of 0.5-3mm. Then stored in an air-tight container to protect them from moisture built-up and fungi infections [21].

250g of dried sawdust samples were placed on a metal mesh located at the bottom of a tubular reactor under 150cm³/min flow rate of purified nitrogen gas. During this period of semi carbonization, the heating rate was kept constant at 10°C/min. The temperature was increased from room temperature to 400°C and kept constant for 2h. The char produced was allowed to cool down at room temperature under nitrogen flow at the same flow rate and stored in air-tight containers.

The char produced was ready for acid activation using 60% phosphoric acid (H₃PO₄) prepared solution. The Impregnation Ratio (IR) was calculated on a volume basis 50/50.

$$\text{Impregnation Ratio (IR)} = \frac{V_{H_3PO_4}}{V_{char}}$$

Here, $V_{H_3PO_4}$ is the volume of phosphoric acid, V_{char} is the volume of the char. The impregnated sample were place inside the tubular furnace with nitrogen gas flow rate of 150cm³/min and heating rate of 10°C/min. the temperature was increased from room temperature to 700°C. Once the activation temperature reached 700°C, the gas flow was switched to CO₂ at the same flow rate and kept constant for 1h.

The prepared activated carbon was cooled to room temperature under nitrogen gas flow maintaining the same flow rate mentioned above, and the activated carbon was washed with de-ionized water until the pH of the washing solution reached 6.5-7. The washed sample of the activated carbon were dried and stored in an air-tight container for

further procedures [22]. Fourier Transform Infrared (FT-IR) spectra of the *Gossweilerodendron balsamiferum* Sawdust before and after adsorption were obtained using an FT-IR (Bruker, Tensor 27 TPR) model spectrometer, within the range of 500 to 4000 cm⁻¹, to explore the number and positions of the functional groups responsible for adsorption.

B) Brewery Effluent sample collection and characterization

The effluent sample was collected from a brewery in Enugu, Nigeria, using 10litres jerry can. The jerry can was filled to the brim with the effluent in order to expel entrapped air. The can was corked and remained sealed until the commencement of the analysis [23] Physicochemical analyses of the effluent sample presented in table 1 were determined following the standard method of water and wastewater purification [24].

Table 1: Characterization of the Brewery Wastewater sample

Parameters	Value
pH	6.54
Turbidity (NTU)	426.00
TDS (mg/l)	505.80
TSS (mg/l)	268.3
BOD ₅ (mg/l)	472.000
COD (mg/l)	851.81
Temperature (°C)	31.5
TS (mg/l)	990
Total hardness (mg/l)	69.0000

C) Batch Studies

Batch experiments were carried out at temperature (30°C) to determine the equilibrium adsorption isotherms. Each batch studies were done by adding different mass (0.2-1.0g) of SACA into 20ml of the effluent and stirring at 150rpm. After shaking the samples, they were subjected to TDSP analysis. For TDSP analysis, they were collected after passing through filter papers in 5 different containers which were labelled accordingly. After filtration of the samples, containers were kept in an oven with 103°C for 24 hours. The subtraction of the weight of containers before and after the test represented the total dissolved solids particles in the brewery wastewater collected.

The amount of adsorption at equilibrium, q_e (mg/g), was calculated by eqn. 1.

$$q_e = \frac{(C_0 - C_e)}{W} V \quad (1)$$

where C_0 and C_e (mg/L) are the liquid-phase concentrations of TDSP at initial and equilibrium time t , respectively. V (L) is the volume of the solution, and W (g) is the mass of adsorbent used.

The TDSP removal percentage can be calculated as follows:

$$\text{Percentage Removal} = \frac{(C_0 - C_e)}{C_0} \times 100 \quad (2)$$

III. RESULTS AND DISCUSSIONS

A) Surface Characterization of SACA

The spectra shown in Fig. 1 display a number of absorption peaks, indicating the complex nature of the surfaces of sawdust. The peak at 3381.2 cm^{-1} before adsorption can be attributed to the hydrogen-bonded OH group of alcohols and phenols [25] and it shifted to 3217.2 cm^{-1} after adsorption. Also, the peak at 1184.3 cm^{-1} before sorption is associated with C-O stretching vibrations in carboxylic acids [26], and it shifted to 1163.1 cm^{-1} after adsorption. These major shifts in band suggest that the alcohols/phenols and carboxylic acid groups were involved in metal binding. In addition, the band at 1597.0 cm^{-1} represents the C=C skeletal stretch in condensed aromatic system and a peak at $754.2.3\text{ cm}^{-1}$ can be assigned to the out-of-plane C-H bending modes of an aromatic compound [27]. Agricultural biomasses mainly consist of lignin, cellulose, hemicelluloses and some proteins which make them effective adsorbents for dissolved solids.

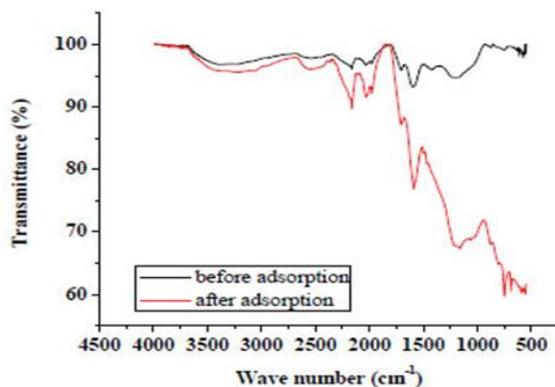


Fig. 1: FT-IR spectra of *Gossweilerodendron balsamiferum* sawdust before and after adsorption

B) Effects of operating Variables

Effect of Contact time: The effect of contact time on the percentage of TDSP removal using various dosages of adsorbent ranging from 0.2 to 1.0g was examined at different time as shown in fig. 2. The result shows that the rate of adsorbed TDSP onto SACA was initially rapid and then it slowed down gradually until equilibrium was attained. It could be explained that a large number of vacant surface site were available for adsorption during the initial stage of adsorption process and after a lapse of time, less remaining vacant sites were available. As Fig. 2 illustrates, uptake attained equilibrium at 40minutes. This result also indicated that the optimum dosage for the TDSP uptake was 0.8g occurring at 89.7%.

Effect of Initial pH: Activated carbons are species with amphoteric character, capable of reacting with either acid or base, depending on the pH of the solution.

The pore walls of activated carbons contained a large number of surface functional groups. The pH dependence of TDSP removal can largely be related to the type of ionic state of these functional groups and also on the adsorbate chemistry

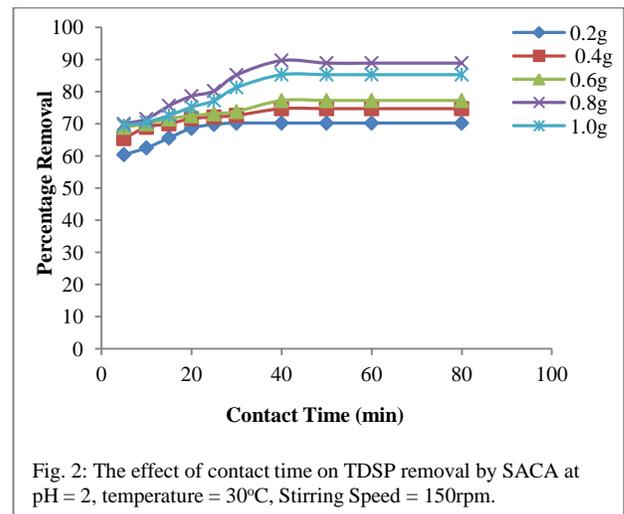


Fig. 2: The effect of contact time on TDSP removal by SACA at pH = 2, temperature = 30°C , Stirring Speed = 150rpm.

in the solution. The solution pH is one of the important parameter for the removal of TDSP from the effluent solution because it affects the solubility of adsorbate, concentration of the counter ions on the functional groups of the adsorbent and the degree of ionization of the adsorbate during reaction [28].

The effect of pH on TDSP adsorption onto SACA was studied through tests carried out on solutions of various pH as shown in fig. 3. It showed that the adsorption of TDSP both increased with decreasing solution pH. This might be attributed to the surface charge of the SACA. Lower adsorption of the adsorbent at alkaline pH was probably due to the presence of excess of hydroxyl ions competing with TDSP anions for the adsorption sites [29]. The effect of pH on the adsorption capacity of SACA may be attributed to the combined effect of the nature of the surface, amount of adsorbed TDSP species. Also clear on fig. 3, percentage adsorption was higher at lower pH, reaching maximum at the pH range of 2-4. Highest removal efficiency (92.1%) was observed at pH 4.

Similar behaviour was reported for the adsorption of hexavalent chromium by sawdust [30] and copper (II) by fly ash [31].

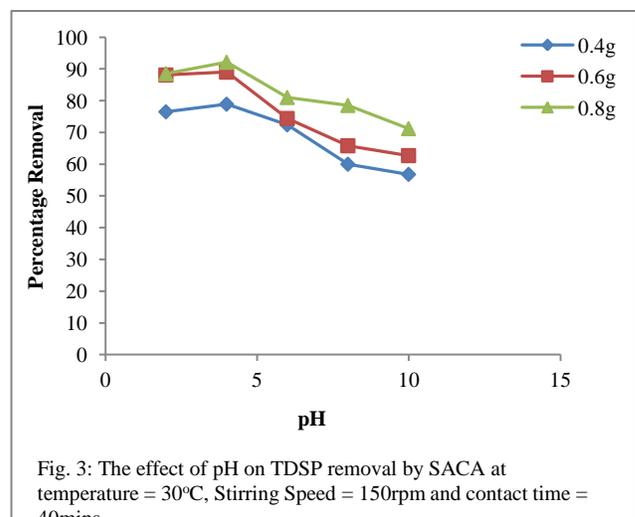
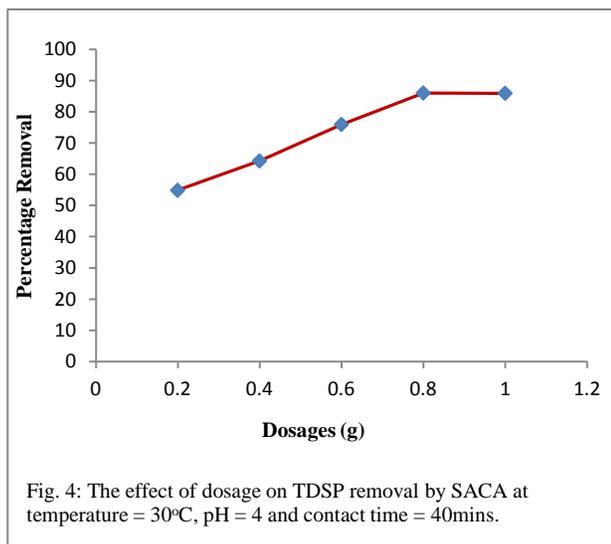


Fig. 3: The effect of pH on TDSP removal by SACA at temperature = 30°C , Stirring Speed = 150rpm and contact time = 40mins.

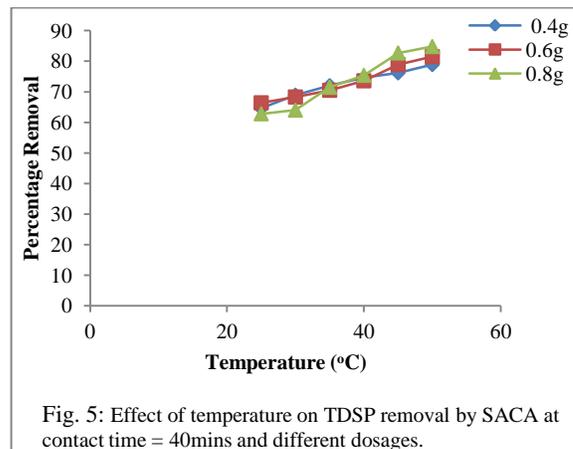
Effect of Adsorbent Dosages: Adsorbent quantity is very essential in adsorption because it determines the capacity of adsorbent for adsorbate removal. The adsorption percentage of TDSP increases with increase in the amount of adsorbent used, the optimum value was at dosage of 0.8g, above which the effect of the adsorbent quantity becomes irrelevant fig. 4. This may be due the saturation of adsorption sites at higher adsorbent dosages.

It was observed that the maximum percentage (86.1%) of TDSP adsorbed was obtained at dosage of 0.8g. the increase in the adsorption efficiency due to increase in dosage at constant volume of effluent can be explained by increasing surface area of the SACA where the adsorption occurs. From fig. 4, the dosage of SACA increase with increase in percentage removal until equilibrium was attained from 0.8 to 1.0g. This may be attributed to attainment of equilibrium between adsorbate and adsorbent under the same operating conditions. The adsorption process reached a saturation point after which no further TDSP adsorption took place. Any further increase in the adsorbent dose after 1.0g will lead to desorption.



Effect of Temperature: Temperature has an important effect on the adsorption process. Adsorption studies as a function of temperature shown in fig. 5, was found that the TDSP adsorption uptake increased with increasing solution temperature from 25 to 50°C, indicating the exothermic nature of adsorption reaction. Maximum adsorption was recorded at 50°C. Similar result was observed by [31].

The improvement in the adsorption capacity might be due to the chemical interaction between adsorbate and adsorbent, creation of some new adsorption sites or the increased rate of intraparticle diffusion of adsorbate molecules into the pores of the activated carbons at higher temperatures [32]. Similar observations was noted, also suggesting that the increase in adsorption capacity with increase in temperature might be due to the possibility of an increase in the porosity and in the total pore volume of the adsorbent, an increase of number of active sites for the adsorption as well as an increase in the mobility of the adsorbate molecules [33].



Adsorption Isotherms: An isotherm is the relationship that shows the distribution of adsorbate between the adsorbed phase and the solution phase equilibrium. The capacity of an adsorbent can be described by its equilibrium sorption isotherm, which is characterized by certain constants whose values express the surface properties and affinity of the adsorbent. The purpose of the adsorption isotherms is to relate the adsorbate concentration in the bulk and the adsorbed amount at the interface [34]. The isotherm results were analyzed using the Langmuir, Freundlich and Temkin isotherms. These three isotherms represent surface adsorption. Surface adsorption is the simplest model of adsorption on a surface in which localized adsorption takes place on an energetically uniform surface without any interaction between adsorbed molecules [35].

Langmuir isotherm equation assumes that fixed individual sites exist on the surface of the adsorbent, each of these sites being capable of adsorbing one molecule, resulting in a monolayer one molecule thick over the entire carbon surface [36]. The Langmuir model also assumes that all sites adsorb the adsorbate equally. The expression of the Langmuir model is given by Eq. (3)

$$q_e = \frac{Q_0 b C_e}{(1 + b C_e)} \quad (3)$$

where C_e (mg/l) is the equilibrium concentration of the adsorbate, q_e (mg/g) is the amount of adsorbate per unit mass of adsorbent, Q_0 and b are Langmuir constants related to adsorption capacity and rate of adsorption, respectively. The linear form of the Langmuir equation can be described by

$$\frac{C_e}{q_e} = \left(\frac{1}{Q_0 b}\right) + \left(\frac{1}{Q_0}\right) C_e \quad (4)$$

The linear plot of specific adsorption (C_e/q_e) against the equilibrium concentration (C_e) (Fig.6) shows that the adsorption obeys the Langmuir model. The Langmuir constants Q_0 and b were determined from the slope and intercept of the plot and are presented in Table 2. The R^2 value (0.998) suggests that the Langmuir isotherm provides a good fit to the isotherm data. A similar observation was reported for adsorption of Copper (II) on fly ash [31], and chromium on sawdust [30]. The essential characteristics of the Langmuir

isotherm can be expressed in terms of a dimensionless constant separation factor R_L [37] given by Eq. (5)

$$R_L = \frac{1}{1+bC_0} \quad (5)$$

where C_0 (mg/L) is the highest initial concentration of adsorbent, and b (L/mg) is Langmuir constant. The parameter R_L indicates the nature of shape of the isotherm accordingly:

Values of R_L	Nature of Isotherm
$R_L > 1$	Unfavourable adsorption
$0 < R_L < 1$	Favourable adsorption
$R_L = 0$	Irreversible adsorption
$R_L = 1$	Linear adsorption

The value of R_L in the present investigation has been found to be 0.012 at 30°C showing that the adsorption of TDSP on SACA is favourable at the temperature studied.

Freundlich isotherm [38] is the earliest known relationship describing the adsorption equation. The isotherm can be used for non-ideal adsorption that involves heterogeneous surface energy systems. The Freundlich isotherm equation assumes that the adsorbent has a heterogeneous surface composed of adsorption sites with different adsorption sites and is expressed by the following equation:

$$q_e = K_F C^{1/n} \quad (6)$$

where K_F (mg/g (L/mg)^{1/n}) is roughly an indicator of the adsorption capacity and $1/n$ is the adsorption intensity. The magnitude of the exponent, $1/n$, gives an indication of the favourability of adsorption. Values of $n > 1$ represent favourable adsorption condition [39, 40, and 41]. To determine the constants K_F and n , the linear form of the equation may be used to produce a graph of $\ln(q_e)$ against $\ln(C_e)$ (Fig. 7):

$$\ln q_e = \ln k_f + \left(\frac{1}{n}\right) \ln C_e \quad (7)$$

Values of K_F and n are calculated from the intercept and slope of the plot (Fig. 7) and are listed in Table 2. The R^2 value (0.996) suggests that the Freundlich isotherm also provides a good fit to the isotherm data. The value of Freundlich exponent n (1.081) is in the range of $n > 1$, indicating a favourable adsorption [42], [43].

Temkin and Pyzhev considered the effects of some indirect adsorbate interactions on adsorption isotherms and suggested that because of these interactions the heat of adsorption of all the molecules in the layer would decrease linearly with coverage [44]. The derivation of Temkin isotherm assumes that the fall in the heat of adsorption is linear rather than logarithmic, as implied in the Freundlich.

The Temkin isotherm has been generally applied in the following form:

$$q_e = \left(\frac{RT}{b}\right) \ln(AC_e) \quad (8)$$

and can be Linearized as:

$$q_e = B \ln A + B \ln C_e \quad (9)$$

where $B = RT/b$, b is the Temkin constant related to heat of sorption (J/mol); A is the Temkin isotherm constant (L/g), R the gas constant (8.314 J/mol K) and T the absolute temperature (K). Therefore, by plotting q_e versus $\ln C_e$ enables one to determine the constants A and B as shown in Fig. 8. The constants A and B are listed in Table 2. The best equilibrium model was determined based on the linear square regression correlation coefficient R^2 . From Table 2, it was observed that the equilibrium sorption data were very best represented by the Langmuir isotherm. The validity of the Langmuir model here, recommended that the adsorption process was monolayer [45] and adsorption of each molecule was equal on each site.

The Freundlich model was found to fit the data a little better than Temkin model, which showed that the adsorption process also has little heterogeneous characteristics. Also, low correlation coefficients ($R^2 < 0.917$) show poor agreement of Temkin isotherms with the experimental data.

Table 2: Langmuir, Freundlich and Temkin isotherm model constants and correlation coefficients for adsorption of TDSP onto SACA

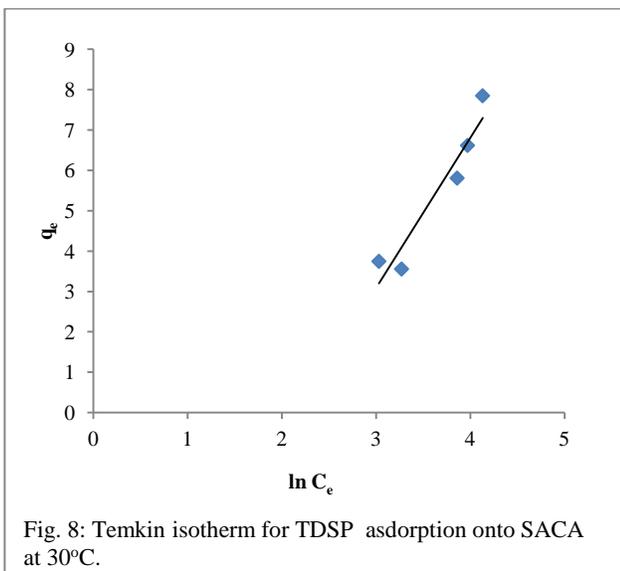
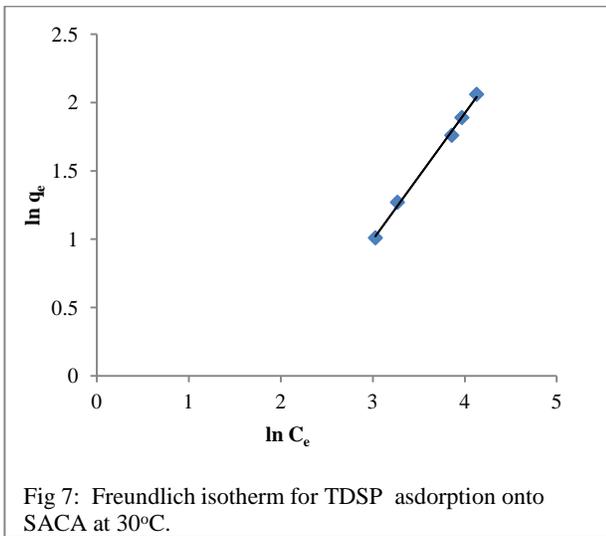
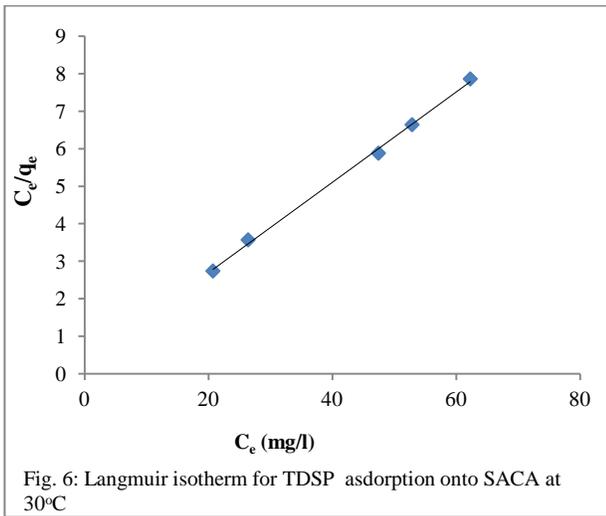
Isotherm	Parameters
Langmuir	
Q_0 (mg/g)	8.40
b (L/mg)	0.389
R^2	0.998
Freundlich	
K_f	0.168
n	1.081
R^2	0.996
Temkin	
A	0.114
B	3.724
R^2	0.917

C) Adsorption Kinetics

The kinetics of adsorption controls the process efficiency [46]. For any adsorption system, study of chemical kinetics is very important so as to determine the rate constants for the reaction and to know how quickly or slowly the reaction is proceeding. In order to evaluate the kinetic parameters, Pseudo first order and Pseudo second order models were implemented to analyze the experimental data.

Lagergren proposed a method for adsorption analysis which is the pseudo-first order kinetic equation of Lagergren [47] in the form:

$$\text{Log}(q_e - q_t) = \text{Log} q_e - \frac{K_1}{2.303} t \quad (10)$$



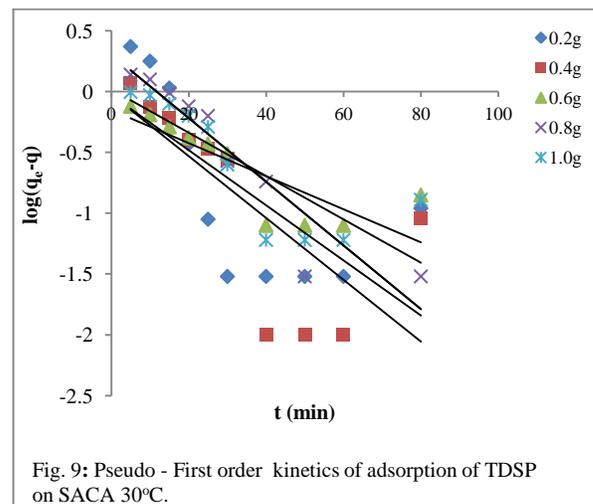
Where k_1 (min^{-1}) is the rate constant of pseudo-first order adsorption, q_e (mg/g) is the amount of adsorbate adsorbed on the surface at equilibrium and q_t (mg/g) is the amount of adsorbate adsorbed at time t . The value of k_1 and q_e for TDSP adsorption by SACA were determined from the plot of $\log(q_e - q_t)$ against t (Fig. 9). The parameters of pseudo-first order model were summarized in Table 3 along with the corresponding correlation coefficients. It was found that the calculated q_e values do not agree with the experimental q_e values (Table 3). Also the correlation coefficient value obtained from the plot was very low. This suggests that the adsorption of TDSP does not follow pseudo-first order kinetics.

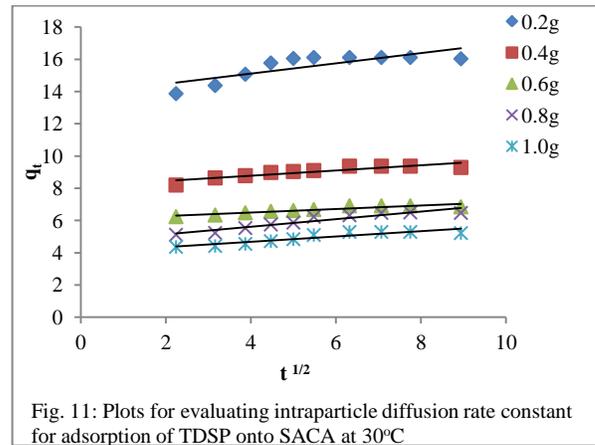
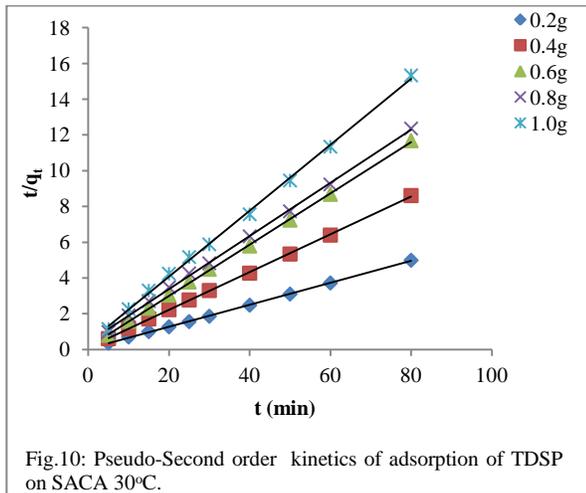
Therefore, the pseudo-second-order kinetic model [41, 48] as shown in Eq. (11) was used to study the adsorption kinetic of the present system.

$$\frac{t}{q_t} = \frac{1}{k_2 q_e^2} + \left(\frac{t}{q_e}\right) t \tag{11}$$

Where k_2 (g/mg min) is the second-order rate constant. The q_e and k_2 can be calculated from the slope and intercept of the plots t/q_t versus t (Fig. 10).

The values of the calculated and experimental q_e together with K_2 with the corresponding coefficients as represented in Table 3 shows that there is an agreement between q_e experimental and q_e calculated values for the pseudo-second order model. Hence, the pseudo-second-order model better represented the adsorption kinetics. The high correlations coefficient and high agreement that exist between the calculated and experimental q_e values of the pseudo-second order kinetic model over the former model proves it best in adsorption of TDSP on SACA. This confirms that the sorption data are well represented by the pseudo-second order kinetics for the entire sorption period. Similar phenomenon has been observed in the adsorption of methylene blue by hazelnut shells and wood sawdust [49].





D) Adsorption Mechanism

In order to gain insight into the mechanisms and rate controlling steps affecting the kinetics of adsorption, the kinetic experimental results were fitted to the Weber’s intraparticle diffusion [50]. The kinetic results were analyzed by the intraparticle diffusion model to explain the diffusion mechanism, the model is expressed as:

$$q_t = K_{id}t^{1/2} + C \tag{12}$$

Where *C* is the intercept and *k_{id}* is the intraparticle diffusion rate constant ($mgg^{-1}min^{-1/2}$), which can be evaluated from the slope of the linear plot of *q_t* versus *t^{1/2}* as shown in Fig. 11.

The calculated intraparticle diffusion coefficient *k_{id}* and intercept *C* values were listed in Table 4. Values of *C* gave an idea about the thickness of boundary layer. It is assumed that, the larger the intercept, the greater the contribution of the surface sorption in the rate-controlling step. The plots of intraparticle diffusion showed that, the lines did not pass through the origin. This implied that the rate limiting process is not only governed by intra particle diffusion. Some other mechanism along with intraparticle diffusion was involved for the whole sorption process [51].

Table 4: Intraparticle diffusion parameter at different adsorbent dosages

Dosages (g)	C	Kid (mgg ⁻¹ min ^{1/2})	R ²
0.2	2.523	0.086	0.968
0.4	0.105	0.105	0.999
0.6	0.136	0.143	0.976
0.8	0.407	0.148	0.999
1	0.393	0.184	0.998

IV. CONCLUSION

This study highlighted the potential of sawdust of *Gossweilerodendron balsamiferum*, an agricultural waste material, to be a low-cost adsorbent for the removing TDSP from wastewater. The equilibrium adsorption is practically achieved in 50min. The fitness of Langmuir's model indicated the formation of monolayer coverage of the sorbate on the outer surface of the adsorbent, with monolayer adsorption capacity of 8.40mg/g at 30°C. The *R_L* value showed that the activated carbon was favourable for the adsorption of TDSP and the unit processes chosen for the study was efficient. The suitability of the Pseudo-first order kinetic and Pseudo-second order kinetic models for the sorption of TDSP onto SACA was also discussed. It was observed that the adsorption kinetics of TDSP obeyed Pseudo-second order adsorption kinetic. The intraparticle diffusion analysis obtained shows the adsorption process as one of the rate determining steps. The present study concludes that the SACA could be employed as adsorbents for the removal of TDSP from wastewater.

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Table 3: Comparison of the pseudo-first order, pseudo-second order adsorption rate constants; also calculated and experimental q_e values obtained at different adsorbent dosages at 30°C

Dosages (g)	Pseudo-First order Kinetics				Pseudo-Second order Kinetics		
	q_e, exp (mg/g)	q_e, cal (mg/g)	K_1 (min^{-1})	R^2	q_e, cal (mg/g)	K_2 (min^{-1})	R^2
0.2	16.14	0.94	0.051	0.485	16.39	0.073	0.999
0.4	9.38	0.95	0.058	0.536	9.52	0.105	0.999
0.6	6.99	0.71	0.03	0.686	6.99	0.15	0.997
0.8	6.5	2.02	0.06	0.885	6.76	0.054	0.999
1	5.35	1.04	0.039	0.676	5.43	0.086	0.998