Adsorption of Maleic and Oxalic Acids on Activated Carbons Prepared from Tamarind Seeds

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Abstract-This paper reports an investigation on the adsorption of maleic and oxalic acids onto activated carbons prepared from tamarind seeds. The activated carbons were prepared by chemical activation method and characterized by Attenuated Total Reflectance-Fourier Transform Infrared (ATR-FTIR) spectroscopy, iodine numbers and pH measurements. Results indicated that the carbons had iodine number and pH values ranging from 259 to 1117.6 mg/g and 6.0 to 8.1, respectively. In addition, the surface functional groups were found to be mainly carbonyls, lactones, pyrones and C=C bonds. The adsorption of the dicarboxylic acids was predicted to be controlled by chemisorption, possibly on a mixture of heterogeneous and homogeneous adsorbing sites, in addition to intraparticle diffusion. Furthermore, the adsorption data were well described by the Langmuir and Freundlich adsorption models. The maximum monolayer adsorption capacities of oxalic acid and maleic acids were found to be 420.12 mg/g and 723.38 mg/g, respectively.Generally, the adsorption process was exothermic and was favourable for all tested activated carbons.

Key words: Maleic acid and oxalic acid adsorption, tamarind seeds, activated carbon, adsorption isotherms.

I. INTRODUCTION

Water pollution resulting from various anthropogenic activities is a worldwide problem that requires a serious attention. It is reported to account for deaths of more than 14,000 people daily [1]. Among the potential sources of ground and surface water pollution are effluents discharged from industrial and agricultural processes. Both organic and inorganic pollutants can be found in wastewaters depending on the nature of the activities carried out at the source. Most organic pollutants found in wastewaters, for instance, originate from effluents discharged from textile, pulp and paper, pharmaceutical, chemical and petrochemical industries. Once in the environment the organic pollutants usually undergo oxidation yielding carboxylic acids including dicarboxylic acids as end products [2]. Examples of the dicarboxylic acids include maleic and oxalic acids which results due to partial oxidation of phenol and its derivatives [3]. It has been reported that high levels of maleic and oxalic acids in potable water cause health problems to humans like kidney stones, uremia, erosion of enamel and mouth, vomiting and hematemesis [4]. In that case elimination or lowering the levels of these acids in wastewaters is not optional.

There are various methods of treating wastewaters contaminated with carboxylic acids. Such methods include catalytic wet air oxidation (CWAO), catalytic ozonation, biological treatments and adsorption[5]. However, each method has its own merits and demerits. For instance, it is evident that removal of maleic and oxalic acids from wastewater by CWAO though efficient, it is expensive and commercially unattractive due to high cost of energy, the use of expensive noble metal catalysts and operation complexity [6]. The degradation of oxalic acid by catalytic ozonation is also expensive and it generates ozone. On the other hand, biological treatment is usually hampered by extreme sensitivity to changes in environmental conditions [7]. Adsorption method in the removal of lower aliphatic carboxylic acids from wastewater is, however, overwhelmingly recommended by the literature [7]. Unfortunately the choice of a cost-effective adsorbent is a big challenge. A good adsorbent is supposed to be cheap, abundant, with high carbon content. Activated carbon is widely reported as a suitable adsorbent for the acids. Unfortunately it is expensive. In an effort to reduce the cost, an attention is now directed towards the use of agrowastes as sources of the activated carbons [8]. However, more studies are still required as there are still numerous unstudied sources of agrowastes that are potentially suitable as raw materials for the production of activated carbons. As a continuation of the search, tamarind (*Tamarindusindica*) seeds, an agrowaste available in most parts of Tanzania, was used in preparing activated carbons and the later were tested in the adsorption of maleic and oxalic acids.

II. MATERIAL AND METHODS

A. Materials and Chemicals

Tamarind (*T. indica*) seeds obtained from Dodoma, Tanzania were used for the preparation of activated carbons. Oxalic acid dihydrate assay 99.8% (RANKEM India) and maleic acid (assay > 99.5% AR) (RANKEM India) were used for preparation of synthetic contaminated water. All other chemicals were used as received.

B. Preparation of Activated Carbons

Three sets of activated carbons were prepared from various parts of tamarind seeds using the chemical activation method described by Matumbo and Mkayula [9]. Potassium hydroxide was used as an activating agent at an impregnation ratio of 1:1. The resultant activated carbons were code-named tamarind seed testa carbon (TSTC), decorticated tamarind seed carbon (DTSC) and tamarind seed as supplied carbon (TSSC), depending on the form of the raw tamarind seed. The carbons were prepared at temperatures ranging from 400 ^{o}C to 800 ^{o}C.

C. Characterization of Activated Carbons

The pH of the prepared activated carbons was determined using a procedure reported by Abdullah *et al*. [10]. On the other hand, the procedure for the determination of iodine number as reported by Sutcliffe Speakman Carbons Ltd [11] was followed. Some minor alterations, however, were made: standardization of sodium thiosulphate was made using potassium iodate instead of metallic copper. The sample weight was 0.2 g. Furthermore, the surface functional groups of the activated carbons were determined by Attenuated Total Reflectance-Fourier Transform Infrared (ATR-FTIR) spectroscopy which did not require any prior processing of the sample.

D. Batch Adsorption Tests

Batch experiments on the adsorption of maleic and oxalic acids were performed by contacting 0.04 g of activated carbon with 50 mL of a known concentration of the acid solution. The mixture was shaken at room temperature for contact times ranging from 5 to 90 minutes, after which the mixtures were filtered through Whatman filter paper No. 42. The amounts of the acid after equilibration were quantified by titrations of the filtrate solutions (10.00 mL) against standard 0.02 M NaOH in triplicate. The adsorbed amounts at time, t, were calculated by using equation (1).

$$q_t = \frac{(C_i - C_t) \times V}{m} \qquad (1)$$

where C_i is the initial concentration (M) of the acid, C_t is the equilibrium concentration (M) of the acid after time, t, (min), q_t is the quantity of acid adsorbed per g of adsorbent (mg/g), V is the volume (mL) of acid used and m is the mass (g) of the adsorbent. The effects of adsorbent dosage and initial concentrations were also determined.

III. RESULTS AND DISCUSSION

A. Physicochemical Properties of the Prepared Activated Carbons

Table 1 summarizes the physicochemical properties of the prepared activated carbons. From the table it can be seen that the percentage yields of the activated carbons decreased with increase in activation temperature. This can be ascribed to an increased loss of volatile organic compounds and carbon burn off with the rise in activation temperature [12]. Furthermore, the different parts of tamarind seed, namely, seed testa, decorticated seed and as supplied seed (i.e., non-decorticated seed), were found to have different yields. Activated carbons from seed testa had consistently higher percent yields than carbons

developed from decorticated seed or a non-decorticated seed (as supplied) at similar activation temperature. This is probably ascribed to higher carbon content and lower volatile organic compounds in tamarind seed testa compared to decorticated seeds or complete seeds. It has been reported that hard woody raw materials produce activated carbons of high yield due to high percent of lignin compared to cellulose and hemicelluloses which easily decompose at 500 ^{o}C [13]. The chemical activation process utilizes a strong solution such as KOH. This penetrates a precursor at elevated temperature and swells it, opening its cellulose structure. On carbonization the chemical acts as a support and does not allow the resulting char to shrink. After the extraction of the chemical from the carbonized char an activated carbon is obtained. The percent yield therefore depends on the amount of the material that is left after the activating agent and other volatile components are freed from the pores [14].

TABLE 1   THE PHYSICOCHEMICAL PROPERTIES OF THE PREPARED ACTIVATED

AC acronym	Activation temp. (ºC)	*ACY (%)	Iodine No. (mg/g)	pH
DTSC1	800	3.6	702	nd
DTSC2	700	8.9	489	nd
DTSC3	600	11.9	446	7.4
DTSC4	400	13.6	259	6.0
TSTC1	800	30.1	1118	8.1
TSTC2	700	32.8	656	7.4
TSTC3	600	34.1	619	6.0
TSTC4	400	37.8	520	5.9
TSSC2	700	16.7	1047	7.3
TSSC3	600	17.1	577	7.0

*ACY(%) – activated carbon yield in percentage.

nd – not determined

Table 1 also shows iodine numbers for the prepared activated carbons. Iodine number in mg/g correlates well with the surface area of an activated carbon in m^2/g available for the adsorption of small sized molecules [15]. The iodine numbers for the prepared activated carbons ranged from 259.4 to 1117.6 mg/g, increasing with increase in activation temperature regardless of the nature of the raw material. As the temperature increased more tarry materials are normally removed from a precursor and more pores are created. As a result the overall porosity of the carbon increases.

Most of the prepared activated carbons had pH values above 7 while a few samples had pH less than 7 (Table 1). The activated carbons with pH greater than 7 are classified as basic carbons whereas those with pH less than 7 are acidic carbons. Generally, the carbons prepared at temperatures above 600 ^{o}C were either neutral or basic. As the temperature increased the basicity also increased. The basic character of the prepared activated carbons can be ascribed to the presence of pyrone-type structures and delocalized *p*-electrons on condensed polyaromatic sheets

(Fig. 1) [16]. The electron-rich Lewis base sites develop as oxygen is removed from the activated carbon surface during heat treatment in an inert atmosphere. The graphene planes of activated carbon act as Lewis basic sites through accepting protons. Generally, all activated carbons with spectra showing absorption bands for pyrone groups (1438 and 1366 cm^{-1}) and C=C stretching for aromatic ring vibrations (1450 to 1320 cm^{-1}) were basic. Nevertheless, activated carbons whose spectra showed lactone groups (1738.8 cm^{-1}) and other oxygen groups, except pyrone groups and aromatic ring vibrations, were slightly acidic or neutral.
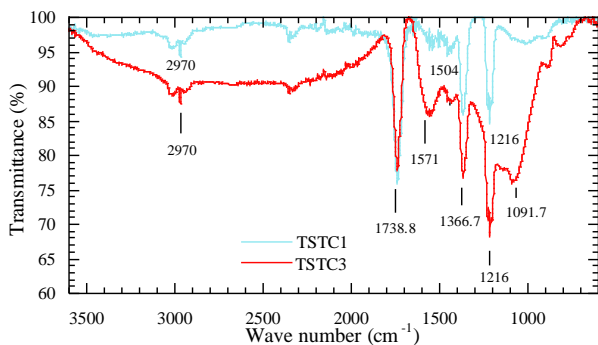

Fig. 1.   ATR- FTIR spectra for TSTC3 and TSTC1 activated carbons, respectively

B.   Effect of Contact Time on the Adsorption of Maleic and Oxalic Acids

The effect of contact time on the adsorption of maleic acid and oxalic acids was determined by equilibrating known concentrations of the acids with known amount of the activated carbon. Only activated carbons prepared from tamarind seed testa were studied because they gave high yields enough to be used for the adsorption studies. Results indicated that the adsorbed amounts of maleic and oxalic acids increased with contact time, reaching equilibrium after 45 and 15 minutes for maleic and oxalic acids, respectively. Fig. 2 shows typical adsorption isotherms for the adsorption of maleic acid on TSTC1 and TSTC3 carbons. As seen from the figure the rate of adsorption was exponential, characterized by a rapid initial removal of maleic acid followed by a nearly constant rate that plateaued near equilibrium. The fast initial uptake of maleic acid can be attributed to the presence of a large number of vacant accessible adsorption sites.After a lapse of time the remaining sites are difficult to be occupied due to repulsive forces between the adsorbate molecules on the adsorbent and the incoming adsorbate molecules. The slower rate of adsorption of the acid at latter stages is attributed to a great decrease of accessible binding sites for maleic acid on the surface of the adsorbent [17]. A similar trend was also observed for the adsorption of oxalic acid on the activated carbons.
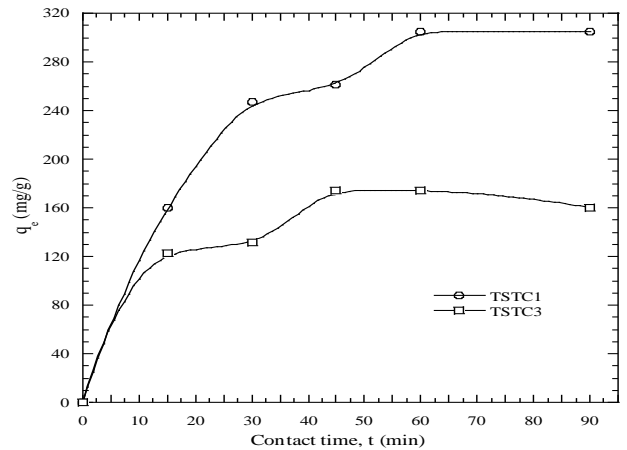

Fig. 2. The effect of contact time on adsorption of maleic acid on TSTC1and TSTC3

C.   Effect of Initial Concentration on the Adsorption of Maleic and Oxalic Acids

The amount of maleic or oxalic acid adsorbed increased exponentially with increase in initial concentration (Fig. 3). However, the percentage removal of the acids was found to decrease with increase in initial concentration. The decrease in percentage removal can be ascribed to a small number of active adsorption sites required for the high initial concentration of the acid.
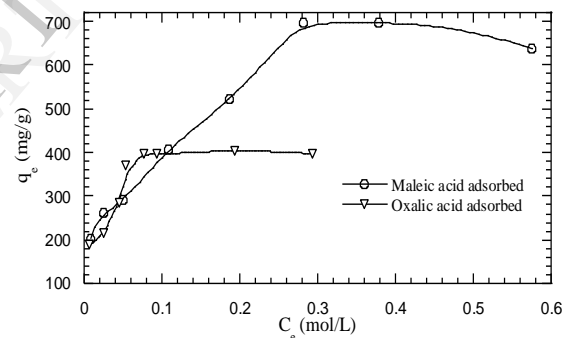

Fig. 3. The effect of initial concentration on adsorption of maleic and oxalic acids on TSTC1

D.   Effect of Adsorbent Dosage on the Adsorption of Maleic and Oxalic Acids

Determination of the effect of adsorbent dosage on the percentage adsorption of maleic or oxalic acid indicated that adsorption increased with increase in adsorbent dosage (Fig. 4). This is explained by the increase in surface area and hence adsorption sites due to the additional adsorbent dosage. However, beyond 0.5 g and 0.7 g of the adsorbent dose for the adsorption of oxalic and maleic acid, respectively, the increase in percent removal was small and it kept on levelling. This was probably due to overlapping of adsorption sites as a result of overcrowding of adsorbent particles at high adsorbent dosage [18].
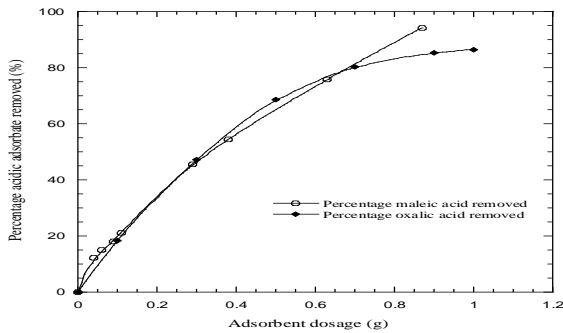
Fig. 4. Effect of adsorbent dosage on adsorption of maleic and oxalic acid on TSTC1

E. Kinetic Study for the Adsorption of Maleic and Oxalic Acids on Activated Carbons

To study the kinetics for the adsorption of maleic and oxalic acid on the prepared activated carbons; data on the effect of contact time were fitted into three kinetic models, namely, the pseudo-second order kinetics, Elovich and intraparticle diffusion models.

Pseudo-second order kinetic model is based on the adsorption capacity of adsorbents and the main assumption is that chemisorption is the rate determining step. In this work, the adsorption data were fitted into pseudo-second order linear integrated form (see equation 2 and 3) [19].

$$t/q_t = 1/h + (1/q_e)t \qquad (2)$$

$$h = k_2 q_e^2 \qquad (3)$$

where h is the initial rate of reaction (mg g^{-1} min^{-1}), q_t is the amount of acid adsorbed (mg/g) at contact time t in minutes, q_e is the adsorption capacity (mg/g), and k_2 is the rate constant for pseudo-second order kinetics (g mg^{-1} min^{-1}). The values of q_e and h for a given initial concentration of the acid were obtained directly from the slope and intercept of a plot of t/q_t versus t (Fig. 5). The value of k_2 was calculated from the obtained value of q_e and h by using equation 3 (Table 2).

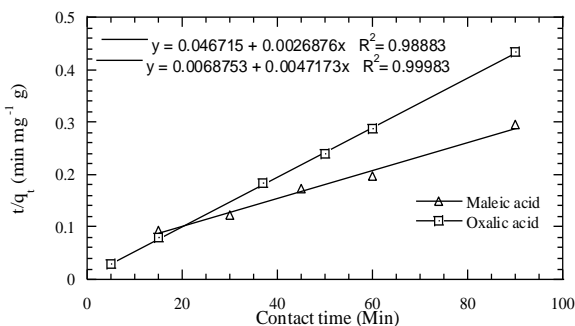
Fig. 5.Pseudo-second order kinetic model for adsorption of oxalic and maleic acids onto TSTC1 at room temperature.

The adsorption of both maleic and oxalic acids fitted very well to pseudo-second order kinetic model with correlation coefficients (R^2) above 0.9. The theoretical adsorption capacity (q_e) obtained through the pseudo-second order model for adsorption of both maleic and oxalic acids were

very close to experimental adsorption capacity ($q_{e(exp)}$). In the case of the adsorption of maleic acid, the q_e values were 372.1 and 177.0 mg/g whereas the corresponding $q_{e(exp)}$ values were 305.3 and 176.4 mg/g for TSTC1 and TSTC3, respectively. In the case of oxalic acid the q_e and $q_{e(exp)}$ values were 212.0 mg/g and 208.0 mg/g for TSTC1, respectively. TSTC1 has a higher adsorption capacity than TSTC3, results that correspond with the observation made by iodine number. Since pseudo-second order kinetics model best fitted the data, it can be suggested that the adsorption process is controlled by chemisorption, an observation olso reported on the adsorption of citric acid on activated carbon based on *Pistacialentiscus* leaves [18].

Elovich equation (equation 4) was also used to analyse the obtained data in its linearized integrated form (equation 5). The equation has been applied satisfactorily to some chemisorption processes and has been found to cover a wide range of slow adsorption rates. It is often valid for systems in which the adsorbing surfaces are heterogeneous.

$$\frac{dq_t}{dt} = \alpha e^{-\beta q_t} \qquad (4)$$

$$q_t = 1/\beta \ln \beta\alpha + 1/\beta \ln t \qquad (5)$$

where α is the initial adsorption rate (mg/g min), β is related to extent of surface coverage and the activation energy for chemisorption (g/mg) and q_t is the amount of acid adsorbed (mg/g) at contact time t in minutes. The Elovich isotherm constants were obtained from a plot of q_t versus ln t as seen in Table 2.

Data on the adsorption of oxalic and maleic acids onto TSTC1 fitted well to Elovich model (Fig. 6) as R^2 values were greater than 0.92. In this particular case, the acids were possibly adsorbed by a chemisorption mechanism on heterogeneous adsorbing surfaces of TSTC1, a conclusion also made by Ekpete *et al.* [20] in the adsorption of chlorophenol onto fluted pumkin activated carbon. The Elovich model also was able to describe the adsorption of maleic acid on TSTC3 but with a correlation coefficient that was less than that predicted by TSTC1. This implies that the adsorbing surfaces were marginally heterogeneous for TSTC3 activated carbon. The differences in heterogeneity of the adsorbing surfaces are probably attributed to the degree of activation.
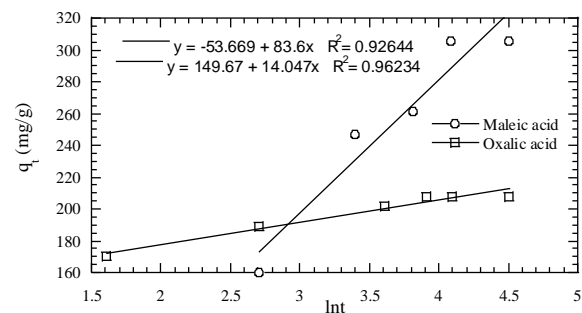

Fig. 6.Elovich model for adsorption of oxalic and maleic acids on TSTC1 at room temperatures

The possibility of intraparticle diffusion of maleic/oxalic acid onto tamarind seeds-based activated carbons was investigated using intraparticle diffusion model (equation 6) [21].

$$q_t = K_{id} t^{1/2} + C \qquad (6)$$

where q_t(mg/g) is the amount of acid adsorbed at time t (min), K_{id} (mg g^{-1} min$^{-1/2}$) is the intraparticle diffusion rate constant and C is the boundary layer thickness. The K_{id} and C were obtained from the slope and intercept of a plot of q_t versus $t^{1/2}$ (Fig. 7), respectively. The obtained values are summarised in Table 2.

TABLE 2. KINETICS CONSTANTS FOR THE ADSORPTION OF MALEIC AND OXALIC ACIDS

| Kinetic model	Parameters	Maleic acid		Oxalic acid
		TSTC1	TSTC3	TSTC1
Pseudo-second order model	q_e(mg/g)	372.1	177.0	212.0
	$q_{e(exp)}$(mg/g)	305.3	176.4	208.0
	h (mg g^{-1} min^{-1})	21.41	31.36	145.45
	k_2 (g mg^{-1} min^{-1})	0.00155	0.001	0.00324
	R^2	0.99	0.97	0.99
	C_i (M)	0.017	0.017	0.0501
Elovich model	β (mg/g)	0.010	0.036	0.071
	α (mg g^{-1} min^{-1})	43.99	48.79	596000
	R^2	0.93	0.63	0.96
	C_i (M)	0.017	0.017	0.0501
Intraparticle diffusion model	K_{id} (mg g^{-1} min$^{-0.5}$)	34.17	18.07	18.24
	C (mg/g)	23.55	26.79	74.20
	R^2	0.94	0.83	0.64
	C_i (M)	0.017	0.017	0.0501
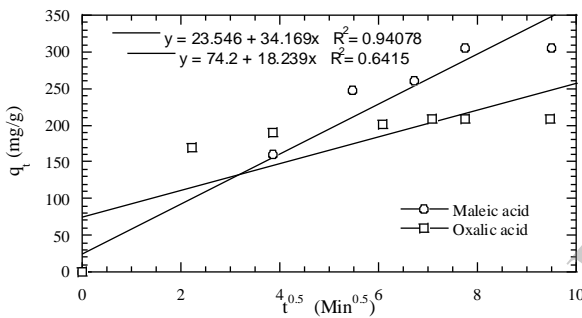
Fig. 7. Intraparticle diffusion model for the adsorption of oxalic and maleic acids on TSTC1

Generally, the intraparticle diffusion model correlation coefficients (R^2) values ranged from 0.64 to 0.94. Whereas the adsorption of maleic acid on TSTC1 could be well described by the intraparticle diffusion model (R^2 = 0.94), the adsorption on TSC3 had R^2 values less than 0.9. On the other hand, data on the adsorption of oxalic acid on TSTC1 did not fit very well to the model (R^2 = 0.64). This implies that pore diffusion was not the rate limiting step in the adsorption process of oxalic acid on TSTC1. As seen in Fig. 7 the linear plots for intraparticle diffusion model did not pass through the origin which is indicative of boundary layer effect and that intraparticle diffusion was not the sole rate limiting step in the adsorption process of maleic and oxalic acids [22, 23]. This suggests that other mechanisms of adsorption involving surface sorption occurred simultaneously with intraparticle diffusion.

F. Adsorption Isotherms for Maleic and Oxalic Acids on the Prepared Activated Carbons

1) Langmuir Adsorption Isotherm

In Langmuir model it is assumed that (a) adsorption sites are energetically homogeneous, (b) there is no interaction between adsorbed molecules, (c) the adsorbed layer is monomolecular layer and (d) adsorption sites are equally accessible to all species [24]. Langmuir adsorption isotherm (equation 7) is normally used in the determination of the maximum adsorption capacity of an adsorbent. In this work, the adsorption data were fitted to a linear form of the Langmuir isotherm (equation 8).

$$q_e = \frac{q_{max} K_L C_e}{1 + K_L C_e} \qquad (7)$$

$$C_e / q_e = 1/(q_{max} K_L) + C_e / q_{max} \qquad (8)$$

where C_e is the equilibrium concentration (mg/L) of maleic or oxalic acid solution, q_e is the amount of maleic or oxalic acid adsorbed at equilibrium per mass of adsorbent (mg/g), K_L is a coefficient related to energy of adsorption and q_{max} is the maximum adsorption capacity per mass of adsorbent (mg/g). From a plot of C_e/q_e versus C_e the values of q_{max} and K_L were determined from the slope and intercept of the straight line, respectively. The values are collated in (Table 3).
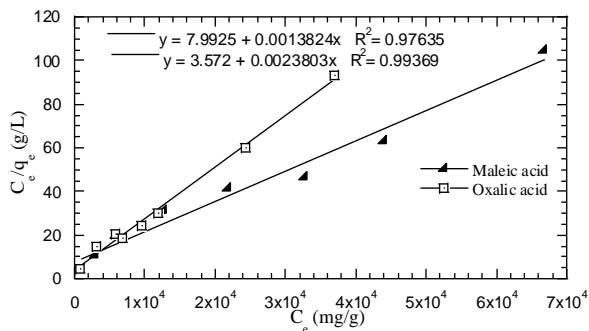
Fig. 8. Langmuir adsorption isotherm of oxalic and maleic acids

The Langmuir isotherm correlation coefficients (R^2) values for the adsorption of maleic and oxalic acids were 0.98 and 0.99, respectively (Fig. 8). The corresponding Langmuir constants related to energy of adsorption for maleic and oxalic acids (K_L) were 1.73×10^{-4} and 6.66×10^{-4} L mg^{-1}, respectively. The high correlation coefficients and K_L values reveal a strong affinity of the acids on energetically homogeneous adsorption sites of TSTC1. Moreover, the maximum adsorption capacities of maleic and oxalic acids on TSTC1 were 723.38 and 420.12 mg/g, respectively, values that were very close to experimental ones.

TABLE 3. ADSORPTION ISOTHERM CONSTANTS FOR ADSORPTION OF MALEIC AND OXALIC ACIDS ON TSTC1

Adsorption model	Parameters	Maleic acid	Oxalic acid
Langmuir isotherm	q_{max}(mg/g)	723.38	420.12
	K_L(L/mg)	0.000173	0.000666
	R^2	0.98	0.99
Freundlich isotherm	K_F (mg/g)(L/mg)$^{1/n}$	21.13	41.09
	$1/n$	0.3	0.2
	n	3.13	4.35
	R^2	0.94	0.79
Temkin isotherm	B_T	129.16	66.13
	K_T(L mg^{-1})	0.00305	0.0201
	b (J mol^{-1})	19000	38000
	R^2	0.89	0.78

2) Freundlich Adsorption Isotherm

Freundlich isotherm is normally applicable to both monolayer adsorption and multilayer adsorption with an assumption that; the adsorbate adsorbs onto the heterogeneous surface with non-uniform distribution of heat of sorption over the surface of adsorbent. In this study, Freundlich isotherm (equation 9) was adopted for analysis of adsorption data for both maleic and oxalic acids on the prepared activated carbons.

$$\log q_e = \log K_F + (1/n)\log C_e \qquad (9)$$

whereby C_e is the equilibrium concentration of the acid (mg/L), q_e is the equilibrium amount of maleic or oxalic acid adsorbed per mass of adsorbent (mg/g), K_F and n are Freundlich constants related to adsorption capacity and adsorption intensity respectively. K_F and $1/n$ were determined from the intercept and slope, respectively, from a plot of $\log q_e$ versus $\log C_e$. The values obtained are shown in (Table 3).
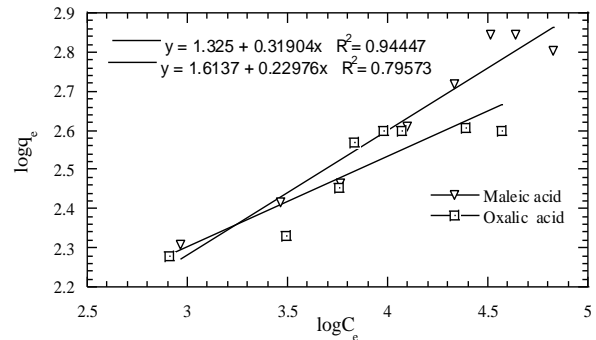

Fig. 9.Freundlich adsorption isotherms for maleic and oxalic acids

The adsorption data could also be described by Freundlich isotherm as the R^2 were close to unity (Fig. 9). This implies that the adsorbing sites were heterogeneous. The values of $1/n$ were less than unity (Table 3) indicating that adsorption was favorable [25]. The isotherms with $1/n$ values less than unity are classified as L–type isotherms and they reflect a relatively high affinity between adsorbate and adsorbent, an indication of chemisorptions.

3) Temkin Adsorption Isotherm

Temkin isotherm assumes that the adsorption energy decreases linearly with the surface coverage due to adsorbent-adsorbate interactions. Temkin isotherm was determined by fitting adsorption data into Temkin isotherm (equation 10) [22, 26].

$$q_e = B_T \ln K_T + B_T \ln C_e \qquad (10)$$

$$B_T = \frac{RT}{b} \qquad (11)$$

where q_e is equilibrium amount of acid adsorbed in mg/g, b is the Temkin constant (J mol^{-1}) related to the heat of sorption and K_T is the Temkin constant (L/g). The constants K_T and B_T were determined from the slope and intercept, respectively, for a plot of q_e versus $\ln C_e$(Fig. 10)and b was determined by using (equation 11).
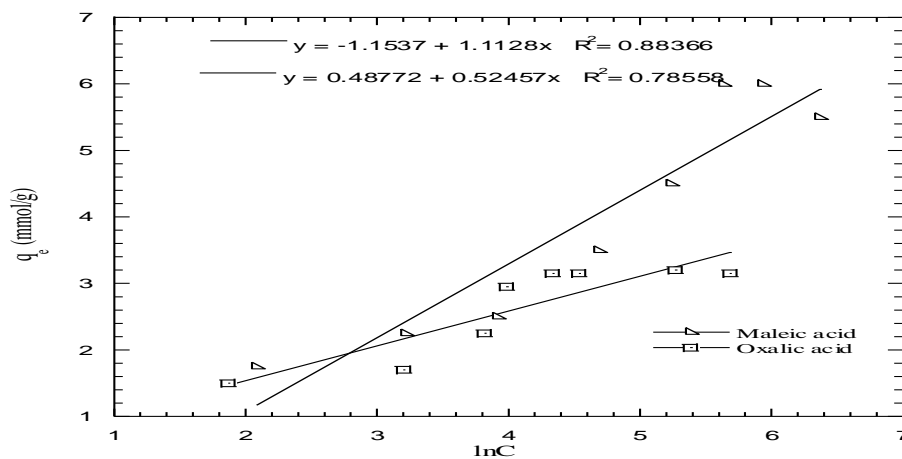
Fig. 10.   Temkin adsorption isotherms for oxalic and maleic acids.

Data on the adsorption of maleic and oxalic acids were also fitted to Temkin model and values obtained are shown in Table 3. The typical R^2 values were 0.89 and 0.78 for the maleic and oxalic acids, respectively. The Temkin constant related to heat of adsorption were 1.9×10^4 and 3.8×10^4 J mol^{-1} for the maleic and oxalic acids, respectively. The values of b for all activated carbon samples were positive. This implies that adsorbate-adsorbent interactions were attractive as predicted also by the Langmuir and Freundlich models. Also it can be inferred that the adsorption process was exothermic [27].

IV.   CONCLUSION

Activated carbons from tamarind seeds were successfully prepared by a chemical activation method, characterized and tested in adsorption of dicarboxylic acids, namely, oxalic and maleic acids.The activated carbons had iodine numbers ranging from 259 to 1117.6 mg/g. ATR-FTIR analysis showed that the carbons consisted mainly of lactones (1739 cm^{-1}), aromatic rings (1568 - 1504) and pyrones (1433 - 1366 cm^{-1}). Treatment of the adsorption data with pseudo-second order, Elovich and intraparticle diffusion models indicated that the adsorption process was controlled by chemisorption, possibly on a mixture of heterogeneous and homogeneous adsorbing sites, in addition to intraparticle diffusion. The data could also be described by Langmuir and Freundlich adsorption isotherms. The maximum monolayer adsorption capacities of oxalic acid and maleic acid were 420.12 mg/g and 723.38 mg/g, respectively. Generally, the adsorption process was exothermic and was favourable for all tested activated carbons.

ACKNOWLEDGMENT

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