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Comparative Batch and Column Evaluation of Thermal and Wet Oxidative Regeneration of Commercial Activated Carbon Exhausted with Synthetic Dye

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ABSTRACT: The efficiency of regenerated spent commercial activated carbon for synthetic dye removal was studied using thermal and wet oxidative regeneration methods. Two types of experiments were carried out, batch adsorption experiments and continous flow (fixed bed) column experiment to study the mechanism of dye removal by the commercial activated carbon. The adsorption equilibrium data were tested using two isotherm models; Langmuir and Freundlich. The goodness of fit of the models to the experimental data was estimated from the three error criteria; R^2, SSE and SE which follow the order for the two models according to best fit; Langmuir (0.959) > Freundlich (0.901), Langmuir (3.889 and 3.118) < Freundlich (9.449 and 4.860).The theoretical maximum adsorption capacity of the virgin commercial carbon (q_{max} = 64.10mgg^{-1}) was compared with those obtained for thermal regeneration method (q_{max} = 61.73mgg^{-1}) and wet oxidative method (q_{max} = 53.72mgg^{-1}). It was in closer agreement with the thermal method than the wet method. The %regeneration efficiency (RE) of the two methods were compared and the thermal method had higher RE (96.30%) than the wet regeneration method with R.E of 83.80%. The column Breakthrough adsorption capacity (q_b) of the commercial activated carbon was 18.52mgg^{-1} which represented 28.89% of the theoretical maximum adsorption capacity of the adsorbent. From the results, the methods compared favourably with those of commercially activated carbon.

Keywords: Activated Carbon, Methyl Red, Chromatography Capacity, Wet and Thermal Regeneration

INTRODUCTION

Water pollution due to discharge of coloured effluents from textile dye manufacturing and textile dyeing mills are one of the major environmental concerns in the world today (Forgacs *et al.,* 2004). Though dyes impart appealing colours to textile fibres, foodstuffs, etc., however, strong colours imparted by the dyes pose aesthetic and ecological problems to the aquatic ecosystems. Because of their complex molecular structures and large sizes most of the dyes are considered non-oxidizable by conventional physical and biological treatments (Weber and Morris, 1963). Thus their decolourization is one of the indispensable processes in wastewater treatment. A number of techniques aimed at preferential removal of different types of dyes from wastewater have been developed (Forgacs *et al*., 2004) among these physico-chemical methods like adsorption (Gupta *et al*., 2004), electrochemical coagulation and photocatalytic decolourization (Muruganandham *et al.,* 2006) are more popular now-a-days. Among all these, adsorption is one of the methods, that is gaining more and more attention because of its easy operations and versatility. It is a useful and simple technique and allows kinetic and equilibrium measurements without the need of any highly sophisticated instrument (Noll *et al*., 1992).

Adsorption Equilibria

Adsorption from aqueous solutions involves concentration of the solute on the surface. As the adsorption process proceeds, the sorbed solute tends to desorb into the solution (Toles *et al*., 2007). Equal amounts of solute eventually are being adsorbed and desorbed simultaneously. Consequently, the rates of adsorption and desorption will attain an equilibrium state. The position of equilibrium is characteristic of the solute, adsorbent, solvent, temperature, and pH. Several models are used for the description of the adsorption data of which the Langmuir and Freundlich models are the ones most commonly used (Emmanuel *et al.,* 2007).

Freundlich Adsorption Isotherm

The Freundlich adsorption equation is perhaps the most widely used mathematical description of adsorption in aqueous systems. The Freundlich non-linear equation is expressed as:

$$q_e = K_F C_e^{1/nF} \quad (1)$$

Where q_e = amount of dye adsorbed per unit mass of adsorbent at equilibrium (mgL^{-1})
C_e = equilibrium concentration of dye (mgL^{-1})
K_F(Lg^{-1}) and $1/n_F$ are Freundlich constants, characteristic of the system, indicating the adsorption capacity and adsorption intensity, respectively.

The Freundlich equation is an empirical expression that encompasses the heterogeneity of the surface and the exponential distribution of sites and their energies.

For linearization of the data, the Freundlich equation is written in logarithmic form:

$$\log q_e = \log K_F + \frac{1}{n \log C_e} \quad (2)$$

The value of 1/n obtained for adsorption of most organic compounds by activated carbon is < 1. The Freundlich equation indicates the adsorptive capacity or loading factor on the carbon, C_e, is a function of equilibrium concentration of the solute. Therefore higher capacities are obtained at higher equilibrium concentrations (Goshwami and Ghosh, 2005).

Langmuir Adsorption Isotherm

Langmuir's model is characterized by the following conditions:

i. The molecules are adsorbed on definite sites on the surface of the adsorbent;
ii. Each site can accommodate only one molecule (monolayer);
iii. The area of each site is a fixed quantity determined solely by the geometry of the surface; and
iv. The adsorption energy is the same at all sites. In addition, the adsorbed molecules cannot migrate across the surface or interact with neighboring molecules.

The non-linear Langmuir equation is expressed as:

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

Where q_e and q_{max} = amount of dye adsorbed at equilibrium and theoretical maximum adsorption of the activated carbon (mg g^{-1}), respectively;
C_e = equilibrium concentration of the dye (mgL^{-1})
b = constant related to the adsorption-desorption energy.

The linearized Langmuir equation is also given as

$$\frac{1}{q_e} = \frac{1}{K_a q_m C_e} + \frac{1}{q_m} \quad (4)$$

Langmuir constants, Ka(mgL^{-1}) and q_m (mgg^{-1}) are related to the energy of adsorption and the adsorption capacity respectively (Weber and Morris., 1963).

Commercially available activated carbon are considered too expensive, due to the use of non-renewable and relatively expensive starting material such as coal, which is unjustified in pollution control application (Tan *et al*., 2007).The use of thermal and wet regeneration techniques as proposed in this study would be welcome development in adsorption technology.

The purpose of this work is study the mechanism and column behaviour of methyl red removal by commercial activated carbon are the effect of the regeneration method on the adsorption

MATERIALS AND METHODS

All the reagents and chemicals used in this study were of analytical grade (M&B, England. The chemicals include; 95% ethanol, trioxonitrate(v)acid, hydrochloric acid, methyl red and commercial activated carbon.

Bulk Density

A 25ml cylinder was filled to a given volume with<2mm mesh size carbon that had been dried in an oven at 80^{0}C overnight (Ahmedna *et al*., 2000). The cylinder was tapped for at least 1-2 minutes to compact the carbon, and then weighed. The bulk density was calculated as (Ahmedna *et al*., 2000).

$$\text{Bulk density}\left(gcm^{-3}\right) = \frac{\text{Weight of dry activated carbon}(g)}{\text{Volume of packed dry material}\left(cm^3\right)} \quad (5)$$

Percentage Attrition

Carbon hardness was determined using a wet attrition test described by (Toles *et al*., 2000). 10-20 mesh carbon were used. One gram of granular activated carbon (GAC) was added to 100 ml of acetate buffer (0.07M sodium acetate and 0.03M acetic acid, pH 4.8) in a 150ml Beaker. The solution was stirred for 24hours at 500rpm. The sample was then poured into a 50mesh (0.30mm) screen and the retained carbon was washed with 250ml of deionized water. After washing, the retained carbon was transffered to a pre-weighed dish and dried at 90^{0}C under vacumm for 24hours. The sample were then removed and allowed to cool in a dessicator. Attrition was calculated as (Bansode *et al*., 2003).

$$\%\ \text{Attrition} = \frac{\text{Initial weight}(g) - \text{Final weight}(g)}{\text{Initial weight}(g)} \times 100\% \quad (6)$$

Regeneration Efficiency (R.E%)

The regeneration efficiency is judged on the extent that it recovered the adsorption capacity of the spent commercial activated carbon. The following method of calculation was employed to quantify the recovery

rate (Martin *et al*., 1984). The formula for calculating regeneration efficiency is expressed as:

$$R.E\% = \frac{A_r}{A_0} x100\% \qquad (7)$$

Where A_r is the adsorption capacity of the regenerated adsorbent, A_0 is the adsorption capacity of the fresh adsorbent and R.E% is the regeneration efficiency of the regenerated commercial activated carbon.

Ash content and pH measurement were done using the methods adopted from Okiemen *et al*. (2004).

Batch Equilibrum Experiment

A stock solution of 1000ppm was prepared (Omomnhenle *et al*, 2006) for methyl red. The experimental solution was prepared by diluting stock with distilled water to obtain 1,2,3,4,5 and 6ppm working standards. 10cm^3 of each working standards of methyl red solution were interacted with 0.1g of the commercial activated carbon in a separate conical flask capped with foil. The flasks were shaken using a thermostatic shaker at 120rpm and constant temperature of 30 ^{o}C. After shaking for the desired time (1h), the samples were filtered, using Wattman filter paper and absorbance reading of the methyl red sample was taken at a pre-determined wavelength of 443nm. The amount of the methyl red adsorbed per unit mass of the commercial activated carbon (mgg^{-1}) was calculated using the mass balance equation given as:

$$q_e = \frac{(C_0 - C_e)V}{W} \qquad (8)$$

Where: C_0 and C_e are initial and equilibrium dye concentrations in mgL^{-1}, respectively,
V = Volume of the solution in litres and W=weight of the activated carbon in (g).
q_e = theoretical maximum adsorption capacity of the activated carbons (mgg^{-1})

Column Adsorption Experiment

The commercial activated carbon (5g) was packed in a vertically set column with an internal diameter of 1.2 and 19.5cm^3 in height to obtain the bed depth, and the column was tapped to remove air bubbles. A 4mgL^{-1} of the methyl red dye solution was poured into the column and replaced at a regular time intervals and the flow rate was estimated as 10ml/min, the pH was adjusted to 5 using 0.1M HCl solution. The column breakthrough capacity was calculated as:

$$q_b = \left[C_0 - \left(\frac{C_b}{2} \right) \right] \frac{Qt_s}{m} \qquad (9)$$

where q_b = breakthrough adsorption capacity (mgg^{-1});
C_o and C_b are the initial and final methyl red concentration in the feed solutions (mgL^{-1});
Q = flow rate (Lmin^{-1});
t_s = service time (minutes); and
m = mass (grams) of the commercial activated carbon.

The correlation coefficient was also calculated using the Four parameter and Four parameter expontential polynomial models which are given as:

aX1+bX2+cX3+dX4+f (10)
Exp (aX1+bX2+cX3+dX4+f) (11)
Respectively,

Where: X1 = Flow rate , X2 = initial conc (C_o) mgL-1, X3 = Bed Depth (m), X4 = C_i/C_e (mgL^{-1}) The variables above are called the dependent variable. Y = operating time (min) which is the independent variable.

Thermal Regeneration of Spent Activated Carbon

Thermal regeneration was based on the approach of Turoti *et al* (2004). Spent sample of commercial activated carbon after column adsorption experiment was placed in a muffle furnace at 650^{0}C for 5 min. The heated sample was removed and poured into iced water bath and excess water was drained and allowed to standard at room temperature. The procedure was repeated at 800^{0}C for 5minutes. The regenerated activated carbon was first washed with 0.1M HNO_3 (Fan *et al*., 2003) to remove surface ash, and rinsed thoroughly with warm water and finally with distilled water to remove residual chemicals (Rahman *et al*., 2005), and until a pH of 6.8 was attained (Ahmedna *et al*., 2000). The regenerated activated carbon was then oven dried at 105^{0}C and stored for re-use.

Wet Oxidative Regeneration of Spent Activated Carbon

Spent commercial activated carbon (5g) was mixed with 5cm^3 of 1M activating agent (H_3PO_4 and HCl). The sample was allowed to stand for 24 h. The regenerated activated carbon was first washed with 0.1M HNO_3, and rinsed with warm water to remove surface chemicals (Rahman and Islam, 2009) and finally with plenty of distilled. The regenerated carbon was then oven dried at 105^{0}C and stored for re-use

RESULTS AND DISCUSSION

Physiochemical Properties of Commercial Activated Carbon

The experimental results obtained on the physical properties of Virgin Commercial activated carbon,

thermal and wet oxidative regenerated spent sample are presented in Table 1.

Bulk Density

Bulk density, an important characteristic of the carbon and is related to the starting material. Bulk density is one of the variables in the design of adsorption columns, which also affects the overall cost of the adsorption process. A higher density carbon will generally not have to be generated as frequently as it will hold more adsorbate per unit volume (U.S. Environmental Protection Agency, 1973). The data on bulk density of the commercial activated carbon (0.57g/m^3) indicates that the CAC has a low bulk density and makes it a good carbon for the design of adsorption column as it would not hold more of the adsorbate (methyl red) per unit volume.

Attrition/ Hardness

This is a measure of the mechanical strength of the carbons and is an important parameter for understanding its relative loss during transportation, handling, and regeneration. From the result displayed in Table 1, the %attrition of virgin commercial activated, was compared to those of spent regenerated commercial activated carbon by thermal and wet oxidative regeneration methods. The %attrition of virgin commercial activated carbon by thermal and wet oxidative regeneration methods are 7.26%, 11.54% and 17.8% respectively. Prior to regeneration of the spent (exhausted) commercial activated carbon, the %attrition obtained for the virgin CAC was below 10% as shown above, which is an indication of good resistance to abrasion. However, after regeneration of the spent CAC, the %attrition obtained for the thermal and wet regeneration methods were above 10% as indicated above.

Comparing the %attrition of the thermal and wet oxidative methods of spent CAC regeneration, it was observed that the thermal method has lower attrition than the wet oxidative method. This is an indication that the thermal method of regeneration of spent activated carbon with about 5% loss is better than the wet method of regeneration of spent activated carbon with upto 10% loss. The variation in the % attrition of the two methods of regeneration of spent activated carbon is likely due to the wet and thermal processes involved in the application of the two methods.

Table 1: Physical and Chemical Characterization of Spent regenerated activated carbon by Thermal and Wet Oxidative methods.

Physical and Chemical Characterization	Virgin Commercial Activated Carbon	Thermal Regeneration	Wet Oxidative Regeneration
Bulk Density(g/m^3)	0.57±0.021	NA	NA
Attrition(%)	7.26±0.028	11.54±0.028	17.8±0.042
Ash(%)	2.00±0.014	6.35±0.002	9.75±0.028
pH	7.40±0.014	6.80±0.028	5.70±0.028
Conductivity(µm)	5.85±0.021	7.08±0.021	11.95±0.014
Regeneration Efficiency(R.E%)	NA	96.30%	83.80%

Key: NA-Not applicable; R^2- Correlation coefficient SSE – Residual sum or sum of square errors SE- Standard error of the estimate

Regeneration Efficiency (R.E %)

The regeneration efficiency is judged on the extent that it recover the adsorption capacity of the commercial activated. However, the regeneration of efficiency of the thermal and wet oxidative methods are 96.30% and 83.80% respectively as shown in Table 1. From the result, it is obvious that the regeneration efficiency of the thermal method is higher than that of wet oxidative method which suggest that the activated carbon by thermal method has more vacant site than the activated carbon by wet oxidative method which also suggest that the thermal method is more efficient than the wet oxidative method. This is attributed to some %loss of the commercial activated carbon due to the steps involved in the application of the two processes. The % loss encountered with wet oxidative regeneration method was higher than that of thermal method as explained earlier.

Ash Content

Ash content is a measure of the minerals as impurities in the carbons mainly derived from the carbon precursor. The Ash content obtained for the CAC from Table 1 is 2.00%. This shows that the Ash Content is significantly low for the commercial activated carbon which is an indication of good precursor for the production of the commercial activated carbon and makes it more desirable for use in adsorption experiment. The Ash content of the virgin commercial activated carbon was also compared with those of spent regenerated activated

carbon by the thermal and wet oxidative methods which have Ash contents of 6.35% and 9.75% respectively. From the above result, it can be seen that the % attrition of wet oxidative method of regeneration is higher than that of thermal regeneration method. This also shows that the thermal method of regeneration of CAC is more favorable and desirable due to its close range with the virgin CAC.

pH

The pH of the carbon directly impacts the adsorption process and affects the final pH of the adsorbent. Therefore a neutral pH is generally preferred. The pHs of the virgin commercial activated carbon was found to be 7.4 and that of thermal and wet oxidative method were 6.8 and 5.70 respectively. The slightly acidic nature of the two regeneration methods is largely due to the washing processes involved during and after regeneration. However, it is observed that the pH of the wet oxidative method of regeneration is higher than that of the thermal regeneration method which is due to the fact that the wet oxidative method is largely acid dependent method of regeneration and the thermal method is partly acidic and high temperature (600-800^{0}C) dependent method. This also makes the thermal regeneration method preferable over the wet oxidative method, as the pH of carbon directly impact adsorption process and the final pH of the experimental solution (adsorbate).

Conductivity

High conductivity of the carbons is undesirable as it interferes in the adsorption process because of the leachable minerals associated with the carbon surface. The conductivity obtained for the virgin commercial activated carbon, thermal and wet oxidative regeneration methods were 5.85 µS/cm, 7.08 µS/cm and 11.95 µS/cm respectively. The higher conductivity of the wet oxidative regeneration method may be due to the treatment processes involved in its application.

Equilibrum Adsorption Isotherms

Studies of adsorption isotherms are essential for the description of how an adsorbent distributes itself between the liquid phase and the solid phase, and are useful to optimize the experimental conditions for obtaining maximum adsorbate uptake (Emmanuel *et al.,* 2007). In this study Langmuir and Freundlich models were applied to the equilibrium uptake data obtained for the adsorption of methyl red and methylene blue solutions. The Langmuir model assumes monolayer adsorption onto a surface containing a finite number of adsorption sites of uniform strategies of adsorption with no transmission of adsorbate in the plane of surface (Emmanuel *et al*., 2007). While the Freundlich model assumes heterogeneous surface energies, in which the energy term in the Langmuir equation varies as a function of the surface coverage (Weber and Morris., 1963). The goodness of fit of the models to the experimental data was checked from the calculated values of the correlation coefficient (R^2), the residual or sum of square error (SSE), and the standard error (SE) of the estimate.

The adsorption isotherms of methyl red is presented in Figure 1, which represents the curve fitting of the equilibrium data of methyl red to the Langmuir and Freundlich isotherm models. The fitting parameters and the corresponding error functions, as obtained by the nonlinear regression analysis using DATAFIT software as presented in Table 2. The shape of the curve and the values obtained for the three error criteria conform more to Langmuir isotherm (Giles *et al*, 1974) than Freundlich isotherm due to the smaller values of SSE, SE and R^2 obtained for the Langmuir model. The maximum adsorption capacity q_{max} of the commercial activated carbon obtained for methyl red adsorption is 64.10 as shown in Table 2. This however, shows that the commercial activated carbon is a good sorbent for the adsorption of organic pollutants. The relatively higher regression value (0.959), obtained for the Langmuir plot indicates fair suitability of this model to present sorbate-sorbent system. The adsorption capacity and intensity of the activated carbon is better described by Freundlich isotherm. The distribution coefficient k_F is related to the adsorption capacity, and the exponent $1/n_F$ is related to surface heterogeneity and adsorption intensity; the lower the $1/n_F$ values, the more favourable the adsorption. The values obtained for K_F and $1/n_F$ for methyl red is in the order 0.270 and 0.534 respectively which is an indication of better adsorption intensity.

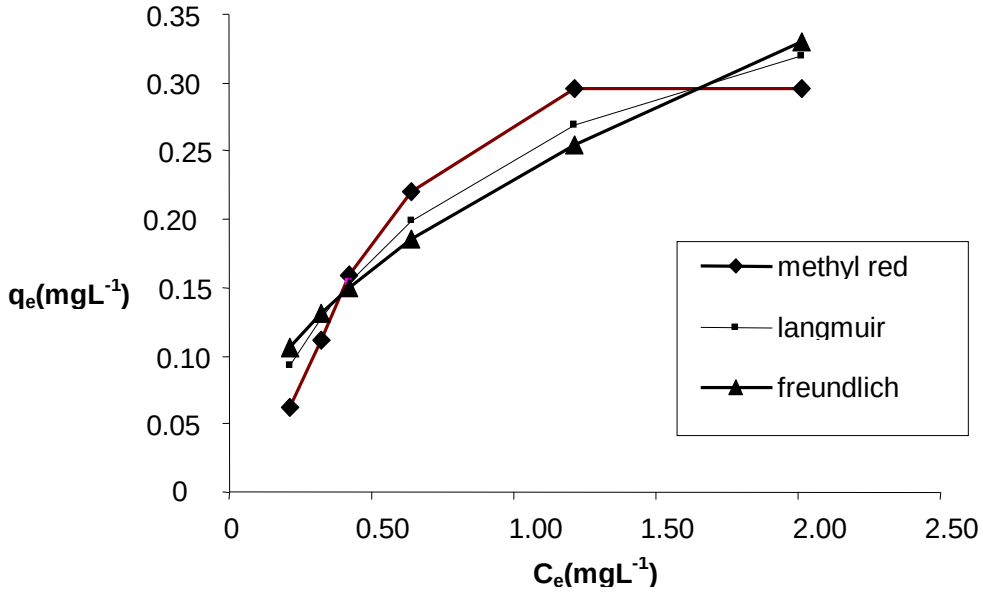

Figure 1: Curve fitting of equilibrium adsorption data with Langmuir and Freundlich isotherm models for methyl red

Fixed Bed Column Adsorption Studies

Adsorption isotherm has been used traditionally for preliminary tests before running column adsorption experiment (Alvarez *et al.,* 2004). However, in this study, batch equilibrium experiment was used as preliminary test prior to the column experiment in order to acertain the maximum theoretical adsorption capacity of the activated carbon. The experiment was carried out at constant conditions, Bed depth (5m), Flow rate (10ml/min), Initial methyl red concentration ($4mgL^{-1}$) and pH 5. Figure 2 shows the breakthrough for the adsorption of methyl red onto commercial activated carbon in terms of C_i/C_e (mgL^{-1}) versus time.

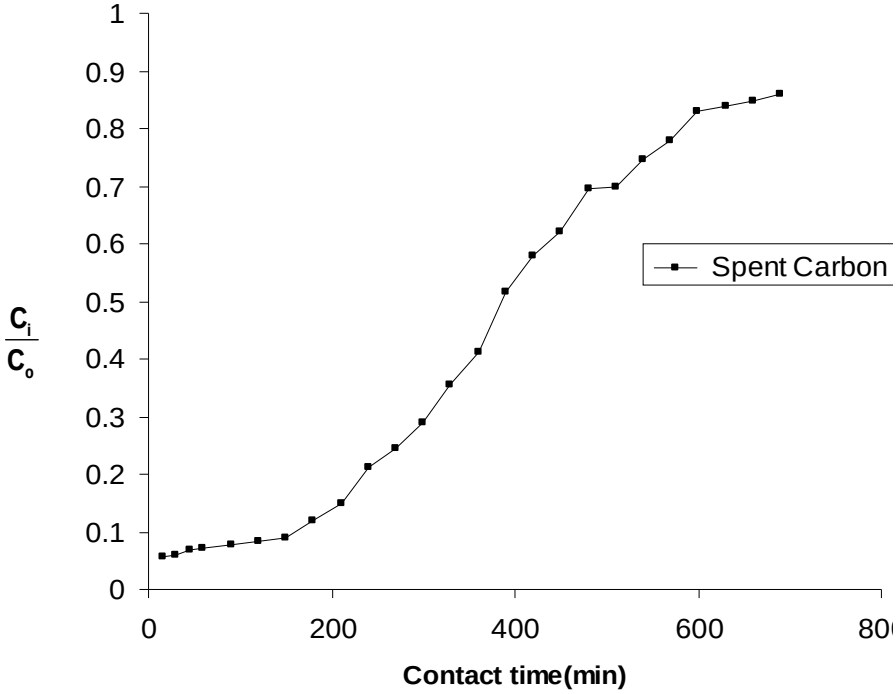

Figure 2: Breakthrough curve for the adsorption of Methyl Red onto Commercial Activated Carbon

The breakthrough maximum adsorption capacity (q_b) of the commercial activated carbon was obtained as 18.52mg/g which represent about 28.89% of the theoretical maximum adsorptive capacity of the commercial activated carbon. This result shows fair suitability for the use of activated carbon in dye removal. Multiple regression models were developed using DATAFIT, Version 9.0 software to stimulate the experimental result shown in Table 2. The model include; four parameter polynomial and four parameter exponential polynomial. The values of calculated coefficient of determination were compared which follows the order; four parameter polynomial (0.965) > four parameter exponential polynomial (0.925) respectively. Further it can be seen that the four parameter polynomial gave the best fit due to its higher R^2 value, than does the exponential polynomial model.

Thermal Regeneration of Spent Commercial activated Carbon

The spent commercial activated carbon from column adsorption experiment was regenerated thermally and the commercial activated carbon obtained was used to carry out Batch equilibrium adsorption experiment so as to compare the result obtained with those of virgin commercial activated carbon so as to access its efficiency after regeneration. Figure 3 represents the Curve fitting of equilibrium adsorption data with Langmuir and Freundlich isotherm models for methyl Red by Thermal Regeneration method.

The result obtained for batch experiment is presented in Table 3. From the result, it can be observed that the R^2 Values obtained for the Langmuir and Freundlich model are 0.941 and 0.891 respectively. When compared to that of the virgin commercial activated carbon with R^2 Values of 0.959 and 0.901 are in close agreement. Similarly, this showed that the regenerated activated carbon by thermal method followed similar pattern of adsorption as the virgin commercial activated carbon.

Wet Oxidative Regeneration of Spent Commercial activated Carbon

The spent carbon was also regenerated by wet oxidative method and the activated carbon regenerated was used to readsorb the dye solution (methyl red) in a batch adsorption to access the efficiency of the spent regenerated activated carbon and also compare it with that of virgin commercial activated carbon. Figure 4 represents the Curve fitting of equilibrium adsorption data with Langmuir and Freundlich isotherm models for methyl Red by Wet Oxidative Regeneration method. The result obtained for the wet oxidative regeneration is presented in Table 4. With R^2 values for the Langmuir and Freundlich Model of 0.926 and 0.854 respectively, however, that of the virgin commercial activated carbon is 0.959 and 0.901 respectively.

Comparison of Thermal and Wet Oxidative Methods for the Regeneration of Spent Commercial Activated

To compare and access the efficiency of the two regeneration methods, the following were put into consideration.

a. The coefficient of Multiple Determination (R^2).
b. The maximum theoretical adsorption capacity (q_{max})
c. Regeneration Efficiency (R.E%)

From the result shown above, the efficiency of the thermal regeneration method is greater than that of wet oxidative regeneration method, which is likely due to the characterization properties as explained earlier.

Table 2: Langmuir and Freundlich Isotherm for Adsorption of Methyl Red on Virgin Commercial Activated Carbon

Equilibrum Data				Langmuir		Freundlich	
C0(mgL-1)	Ce(mgL-1)	(C0- Ce)mgL-1	qe(mgL-1)	Parameters	Value	Parameters	Value
0.891±0.021	0.211±0.014	0.680±0.014	0.068±0.014	qmax(mgg-^{1})	64.10	KF(Lg-^{1})	0.270
1.693±0.021	0.395±0.014	1.244±0.014	0.124±0.014	b	0.827	1/n	0.534
2.117±0.014	0.497±0.021	1.620±0.021	0.162±0.021	RSS	3.889	RSS	9.449
3.041±0.028	0.643±0.021	2.378±0.021	0.237±0.021	SE	3.118	SE	4.860
4.495±0.014	1.512±0.014	2.983±0.014	0.298±0.014	R^2	0.959	R^2	0.901
5.311±0.021	2.343±0.014	2.968±0.014	0.296±0.014				

Table 3: Langmuir and Freundlich Isotherm for Adsorption of Methyl Red on Spent Regenerated Commercial Activated Carbon by Thermal Method

Equilibrum Data				Langmuir		Freundlich	
C0(mgL-1)	Ce(mgL-1)	(C0- Ce)mgL-1	qe(mgL-1)	Parameters	Value	Parameters	Value
0.994±0.014	0.242±0.021	0.752±0.021	0.075±0.021	q_{max}(mgg^{-1})	61.73	KF(Lg^{-1})	0.293
1.863±0.021	0.321±0.014	1.542±0.014	0.154±0.014	B	1.005	1/n	0.553
2.742±0.014	0.497±0.028	2.245±0.028	0.224±0.028	RSS	4.341	RSS	8.087
3.622±0.014	0.833±0.014	2.789±0.014	0.278±0.014	SE	3.294	SE	4.496
4.97±0.028	1.212±0.028	3.758±0.028	0.375±0.028	R^2	0.941	R^2	0.891
5.741±0.028	1.916±0.014	3.825±0.014	0.382±0.014				

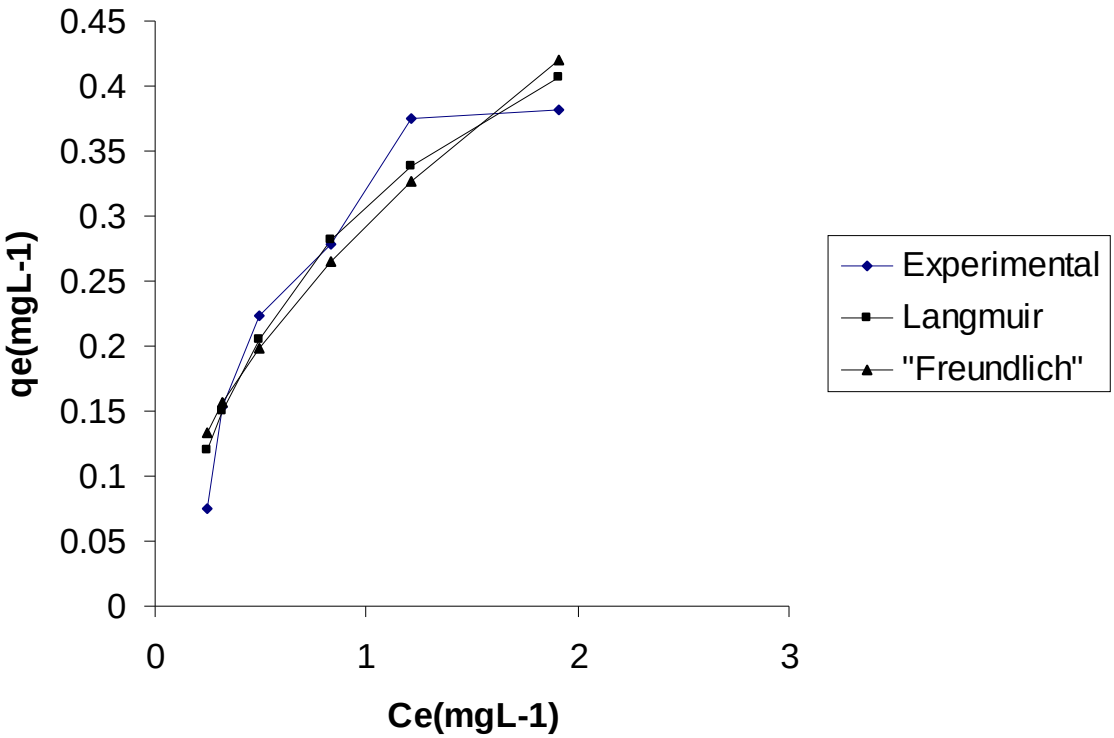

Figure 3: Curve fitting of equilibrium adsorption data with Langmuir and Freundlich isotherm models for methyl Red by Thermal Regeneration method

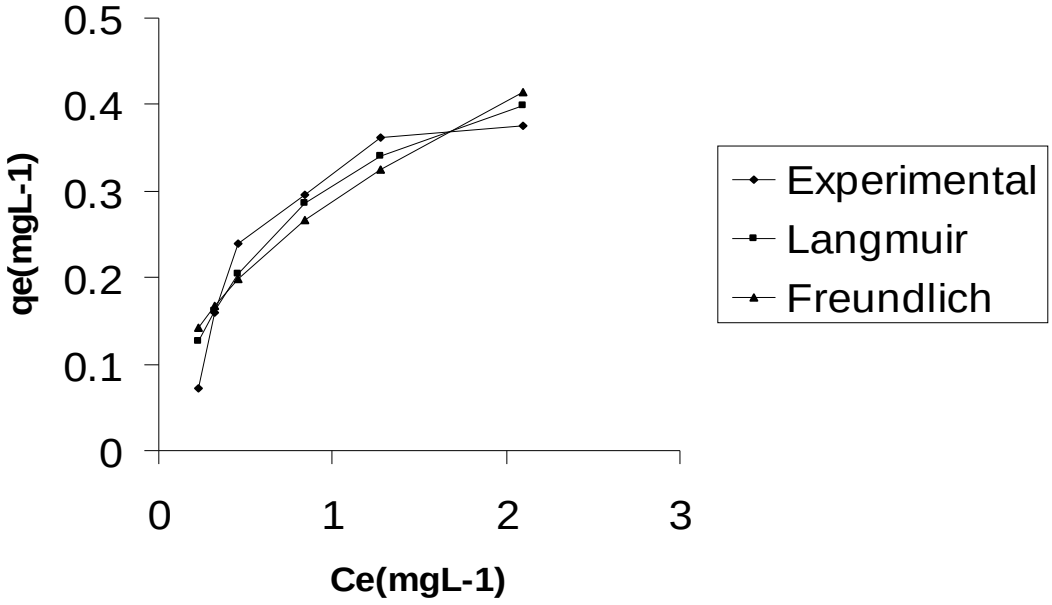

Figure 4: Curve fitting of equilibrium adsorption data with Langmuir and Freundlich isotherm models for methyl Red by Wet Oxidative Regeneration method

Table 4: Langmuir and Freundlich Isotherm for Adsorption of Methyl Red on Spent Regenerated Commercial Activated Carbon by Wet Oxidative Method

Equilibrum Data				Langmuir		Freundlich	
C0(mgL-1)	Ce(mgL-1)	(C0- Ce)mgL-1	qe(mgL-1)	Parameters	Value	Parameters	Value
0.954±0.028	0.226±0.028	0.728±0.028	0.072±0.028	qmax(mgg^{-1})	53.72	KF(Lg^{-1})	0.290
1.911±0.028	0.319±0.021	1.592±0.021	0.159±0.021	b	1.360	1/n	0.624
2.863±0.042	0.456±0.014	2.409±0.014	0.240±0.014	RSS	5.152	RSS	1.023
3.799±0.042	0.840±0.028	2.959±0.028	0.295±0.028	SE	3.589	SE	5.058
4.898±0.028	1.274±0.014	3.624±0.014	0.362±0.014	R^2	0.926	R^2	0.854
5.862±0.014	2.101±0.028	3.761±0.028	0.376±0.028				

CONCLUSION

The experiment has shown that, batch equilibrium studies for the adsorption of methyl red and methylene blue dye solution onto commercial activated carbon, correlated well with both Langmuir and Freundlich model. Also, maximum theoretical adsorptive capacity obtained for the virgin commercial activated carbon was in close agreement with the thermal method of regeneration than the wet oxidative method. It was also found that, regeneration efficiency obtained for thermal method was found to be higher than wet regeneration method.

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