

CHEMICAL AND PHYSICAL PREPARATION OF ACTIVATED CARBON USING RAW BAGASSE PITH FOR CATIONIC DYE ADSORPTION

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ABSTRACT

Agriculture wastes like sugarcane bagasse are available in large quantities in Egypt. Various adsorbents from natural materials, industrial waste materials, agricultural by-products, and biomass based activated carbon can be used in the removal of various dyes. Raw Bagasse pith (RBP) was used to prepare activated carbon (AC) using phosphoric acid (H_3PO_4) as a chemical activating agent. The raw BP and the synthesized adsorbent were characterized by Fourier transform infrared (FTIR) spectroscopy and scanning electron microscope (SEM). The effectiveness of AC prepared in adsorption of methylene blue (MB) has been studied as a function of adsorbent type, initial dye concentration and contact time. The effects of the initial dye concentration and contact time were evaluated. Adsorption isotherm models - Langmuir, Freundlich and Temkin were used to simulate the equilibrium data. Langmuir equation was found to have the highest value of R^2 compared with other models. Furthermore, it was found that sugarcane bagasse have a high adsorptive capacity towards MB.

Keywords: activated carbon, agriculture waste, cationic dye

1. Introduction

Dye production industries and many others industries which used dyes and pigments generate, characteristically high in colour and organic content. About 10,000 different commercial dyes and pigments exist and over 7×10^5 tones are produced annually worldwide (Gong *et al.*, 2005). In textile dyeing processes, a large volume of dye contaminated effluent is discharged and it is estimated that 10–15% of the dye is lost in the dye effluent. The effluents of these industries are highly colored and the disposal of these wastes into receiving water causes damage to the environment as they may significantly affect photosynthetic activity in aquatic life due to reduced light penetration and may also be toxic to some aquatic life due to the presence of metals, chlorides, etc.(Zollinger, 1987). Dyes are synthetic organic compounds with a chemical complex

structure that are stable to light, heat, oxidizing agents and resistant to aerobic digestion (Crini, 2006; Wu *et al.*, 2008). The wastewater generated by the processes of dyes industries like tannery, textiles, paper and plastics usually contains up to around 10% of used dye (Forgacs *et al.*, 2004). Dyes are stable in the receiving environment and posing a serious threat to human and environmental health (Crini, 2008). One of the most famous cationic dyes is methylene Blue (MB). MB is a heterocyclic aromatic chemical compound with a molecular formula of $C_{16}H_{18}N_3ClS$. It has the favorable characteristics of bright color and simple application techniques. MB is used extensively in dyeing natural fibers such as cotton and silk. It can cause eye burns by direct contact and nausea, vomiting, profuse sweating, mental confusion and methemoglobinemia by ingestion (Gusmãoa *et al.*, 2012). Accordingly, to protect humans and the receiving ecosystem from contamination, the dyes must be removed from the wastewater before being released into the environment. Various methods of dye removal including aerobic and anaerobic microbial degradation, coagulation, chemical oxidation, membrane separation, electrochemical treatment, filtration, flotation, hydrogen peroxide catalysis, and reverse osmosis have been proposed from time to time. Municipal aerobic treatment systems were found to be ineffective in the removal of dyes because dye molecules are resistant to biodegradation (Lazaridis *et al.*, 2003; Moussavi *et al.*, 2011). Different chemical advanced oxidation processes have been shown to be efficient for the degradation of several classes of dyes but they are expensive and economically non-attractive. Adsorption is one of the most efficient methods and the main adsorbent used for this purpose is activated carbon due to its excellent adsorption capability (Moussavi *et al.*, 2011). However, the production of activated carbon is complex and expensive, making this technology non-efficient. Accordingly, a critical challenge is finding a low-cost adsorbent that is locally available with high removal capacity so adsorption can successfully compete with other dye removal techniques (Rachakornkij *et al.*, 2004).

The sorption of dye onto agricultural by-products is becoming a potential alternative for inorganic/organic removal from aqueous solution. It is economic, environmental friendly, efficient for dye removal and is able to replace the most widely used commercial activated carbon. Waste materials and raw agricultural solid wastes from forest industries such as bark and sawdust have been applied as adsorbents for dye removal. Agricultural by-products are available in large quantities around the world, as wastes (Foo *et al.*, 2011).

Natural material like wood, peat, agricultural waste and by-product such as shells of almond and hazelnut, sawdust corncob, rice husk and sugarcane bagasse have been studied to adsorb synthetic dyes. The native exchange capacity and general sorption characteristics of these materials derive from their constituents, which contain a variety of functional groups that can adsorb certain contaminants in water (Tseng, 2002). Agricultural waste materials are abundant and have been proven to be good low cost adsorbents due to their easy conversion to a value-added product. These materials have been used as adsorbent without any chemical modification. In addition, the chemical modification can introduce functionality to these solid supports, increasing their adsorption capacity and efficiency (Devaprasath *et al.*, 2007; Miretsky *et al.*, 2010). Sugarcane bagasse is an excellent solid support because it is inexpensive in comparison to other solid support, high efficiency and easy to obtain. Beside, owing to the increase of bioethanol production bagasse has been burned to produce steam and energy for the process: nevertheless, this residue produces ecological problems due to its low natural degradation rate and because it is commonly eliminated by burning, thereby becoming a source of atmospheric pollution. These results have encouraged us to continue exploring the potential of a BP to remove contaminants from water such as dyes that are usually found in wastewater (Litza *et al.*, 2013). The composition of sugarcane bagasse is 40-50% cellulose, 25-30% hemicelluloses, and 20-25% lignin (Gusmãoa *et al.*, 2012).

Activated carbon is the most popular for the removal of pollutants from wastewater among all the sorbent materials proposed (Ramakrishna *et al.*, 1997; Babel *et al.*, 2003). In particular, the effectiveness of adsorption on activated carbons for removal of a large variety of dyes from wastewaters has made it an ideal alternative to other expensive treatment options (Ramakrishna *et al.*, 1997).

The main purpose of the present study was to explore the capability of activated carbon from raw BP to remove a basic model dye, MB, from liquid media under different experimental conditions. Effects of main parameters were also studied for MB removal. In this study, three models (Langmuir, Freundlich and Temkin) Annadurai *et al.*, 2002; El-Geundi, 1991; Miah *et al.*, 2010; Annadurai *et al.*, 1999; Zhao *et al.*, 1989) have been used to describe the sorption process of MB onto sugarcane bagasse.

2. Material and method

2.1 Materials

Bagasse was obtained from a cane mill. Bagasse is an extremely inhomogeneous material comprising around 30-40% of "pith" fiber (inner fiber) and "stem" fiber (outer layer). In this study the two portions was separated and pith bagasse (BP) was taken as the primary material. Pith bagasse composed mainly of cellulose, lignin, hemicelluloses, wax and ash.

MB with a molecular formula of $C_{16}H_{18}N_3ClS$ was purchased from Nice Chemicals Pvt. Ltd. The structure of MB is shown in Fig. 1. The MB used in the present study has a molecular weight of 319.85 with its maximum absorbance at a wavelength of 655 nm. Pure H_3PO_4 (85%) aqueous solutions was purchased from Riedel-de Haen.

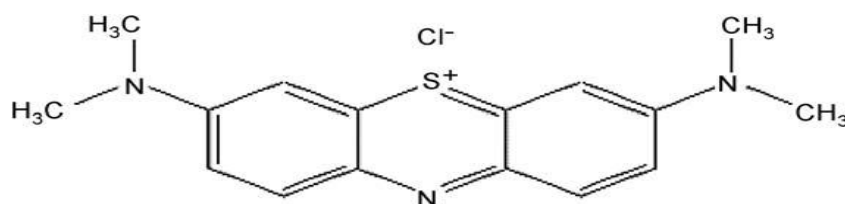


Figure. 1. The structures of methylene blue dye.

2.2 Preparation of adsorbent material

(1) Raw bagasse

Firstly pith bagasse was washed thoroughly with tap water to remove dust particles, and then boiled in distilled water for one hour to remove the sugar residue in the bagasse. After that the washed bagasse was filtrated and exposed to sunlight then dried on an oven at 60 °C until reach to constant weight. Dried bagasse was crushed in a blender and sieved to obtain a uniform grain size. Finally, the sieved material stored in vacuum desiccators for further use and labeled as raw bagasse pith (RBP).

(2) Thermal activation

Activated carbon was prepared from RBP by only applying thermal affect and this achieved by put the sample in steel tube and put this tube in muffle furnace (Barnstead Thermolyne) for carbonization. Carbonization temperature was 600 °C for 1 hr. The carbonized material stored in vacuum desiccators for further use and labeled as physical carbon (PC).

(3) Chemical activation

Activated carbons using RBP was prepared by phosphoric acid. For activation, the RBP was subject to digestion with phosphoric acid by boiling it in 40% phosphoric acid for one hour (mass ratio of raw bagasse pith to phosphoric acid 1:9.8) by using mechanical stirrer with heater. The mixture was filtrated, washed with distilled water then let it dry in air. Treated material putted in muffle furnace for carbonization. Varying the

carbonization temperature (400, 500, 600 and 700 °C) for 1 hour. The carbonized material stored in vacuum desiccators for further use.

2.3 Characterization of bagasse pith and activated carbon

Surface group information of adsorbent was detected using the pressed potassium bromide (KBr) pellets containing 5% sample by FTIR spectrometer (Shimadzu, FTIR-8400S, Japan) in the scanning range of 4000 – 400 cm⁻¹. The morphologies were obtained with a scanning electron microscope (JEOL, model JSM-6360 OLA).

2.4 Preparation of dye solution

MB was used to prepare the synthetic wastewater solution. An accurately weighed quantity of MB (1 g) was dissolved in 1 liter distilled water to prepare the stock solution (1000 ppm). Experimental solutions of the desired concentrations were obtained by successive dilutions. These solutions were then properly wrapped with aluminum foil and stored in a dark place to prevent direct sunlight, which may cause de-composition.

2.5 Batch experiment

Sorption experiments were carried out by agitating certain amount of different types of sorbent (RBP, PC and chemical activated carbon at different temperatures) in 50 ml of varying concentration of dye solution (10, 15, 25 and 30 ppm) in an incubator (MAXQ 4000 Incubator shaker) at certain speed for 1 h at room temperature. After that, the mixtures were filtered and the dye concentrations in the supernatant solutions were analyzed using a Spectrophotometer (Ultropec 2000 UV/visible). Then concentrations of residual dye solutions were measured by monitoring the absorbance changes at a wavelength of maximum absorbance ($\lambda = 665$ nm) for MB dye. The amount of dye sorbed at any time, q_t , was calculated from;

$$q_t = V(C_o - C_t)/W \quad (1)$$

At equilibrium, $q_t = q_e$ and $C_t = C_e$; therefore the amount of adsorbed dye, q_e was calculated from

$$q_e = V(C_o - C_e)/W \quad (2)$$

where C_o , C_t and C_e are the initial concentration, concentration at any time and equilibrium concentrations of dye solution (mg l⁻¹), respectively, V is the volume of the solution (l), and W is the mass of adsorbent (g) (Devaprasath, 2007). The dye removal percentage can be calculated from this equation,

$$\% \text{ Removal} = (C_o - C_t)/C_o * 100 \quad (3)$$

2.6 Effects of initial dye concentration and contact time

MB in water solutions having different concentrations (10-30 ppm) is added with constant dose 0.1 gm of adsorbent respectively for samples. The mixture stirred at 200 rpm and room temperature for different time (5-120 min.), to test the effect of initial concentration and contact time on the adsorption process. It is filtered and colorimetric readings are noted for each solution at equilibrium.

3. Results and Discussion

3.1. Characterization of sugarcane bagasse and its activated carbon

The textural and chemical properties of bagasse and which resulting from activation of bagasse were characterized. These variables are important in the adsorption properties of these adsorbents. The characteristics of bagasse and its activated carbon were made by FTIR and Scanning electron microscope.

3.1.1 Using FTIR spectroscopy

In order to understand the changes in the chemical structure after pretreatment, infrared spectra (Figure 2) of the untreated and pretreated samples were obtained. The broad band centered at 3392 cm^{-1} is attributed to symmetric and asymmetric stretching vibrations of O-H absorbed water molecules. Also the band observed at 3392 cm^{-1} is characteristic of OH groups present in lignin and carbohydrates. The weak band at 2910 cm^{-1} could be attributed to C-H aliphatic axial deformation in CH_2 and CH_3 groups from cellulose, lignin and hemicelluloses. The relative absorbance of the bands of OH groups was at 1047 cm^{-1} (OH stretching). The medium band at 1632 cm^{-1} is attributed to C=C aromatic skeletal vibration. This band is generally found in the lignin aromatic structure. The band at 1702 cm^{-1} is referred to the acetyl groups present in the hemicelluloses. The peak at 1363 cm^{-1} is attributed to the vibration of phenolic group. The peak at 1047 cm^{-1} is corresponded to the C-O-C (ester, ether and phenol). The strong band at 1702 cm^{-1} in pretreated sugarcane bagasse is assign to C-O stretching in cellulose, hemicelluloses and lignin. The weak band at 1253 cm^{-1} is attributed to the C-O stretching of phenol. The strong band at 585 cm^{-1} is attributed to the C-H bend. The results indicated that thermal and acidic treatment causes the degradation of fiber structure of cellulose and lignin to greater extent. Figure 2 shows higher values of relative absorbance in the case of untreated samples as compared to pretreated samples. This result could be attributed to the chemical changes observed when sugar cane bagasse is pretreated with phosphoric acid and heat (Kaur *et al.*, 2013).

The phosphoric acid modified samples have peaks at $\sim 1150\text{ cm}^{-1}$ and 1000 cm^{-1} which could be from C-O-P and P-O respectively (Liou, 2010; Puziy *et al.*, 2005).

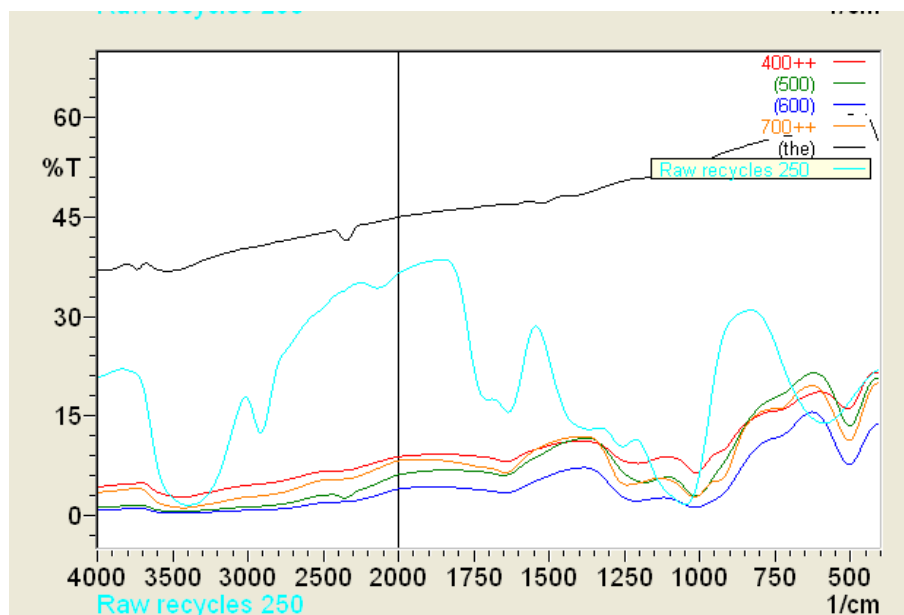


Figure 2. FTIR spectra of modified and unmodified sugarcane bagasse

3.1.2 Using SEM

After examination of the SEM micrograph, the presence of heterogeneous and highly porous cavities over the surface of raw sugarcane bagasse were identified. This indicates good possibility for the pollutants to be adsorbed.

Comparison of the micrographs before and after adsorption of MB are shown in Fig. 3 (a, b) and Fig. 4 (a, b), respectively. It showed various important changes the adsorption of MB onto the raw bagasse pith led to the formation of a monolayer of MB molecules over the surface of the RBP (molecular cloud of uniform thickness)

and various pores and cracks characteristics of the RBP before adsorption were filled by RBP molecules, showing the adherent surface of the RBP adsorbent (Kumar *et al.*, 2011; Bulut *et al.*, 2006).

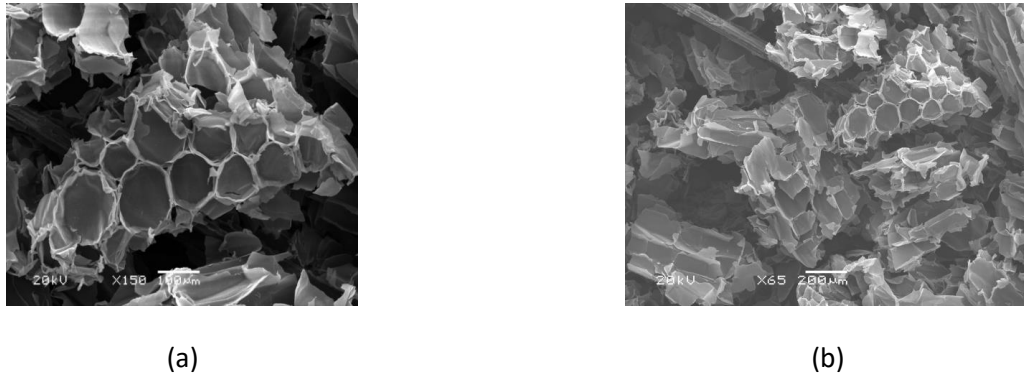


Figure 3. Raw Bagasse

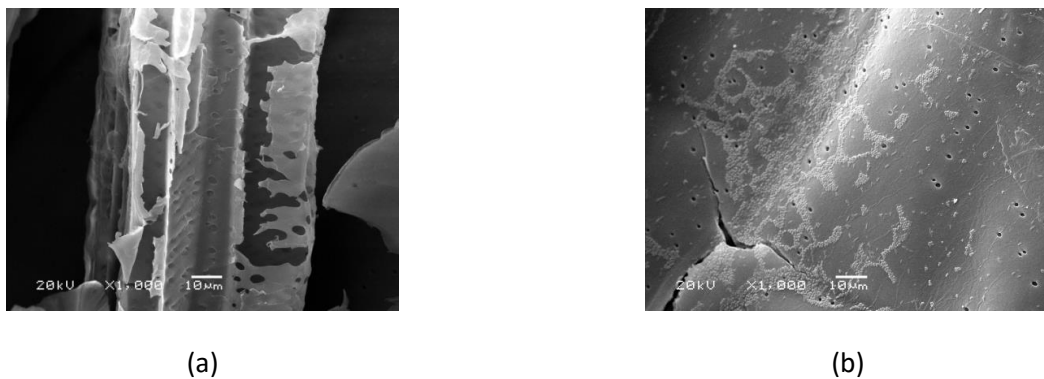


Figure 4. Adsorbed raw

SEM micrographs were used to determine the morphological changes in fiber structure and surface that occur due to the physical and chemical modification of sugar cane bagasse. Scanning electron image of the activated carbon which prepared from bagasse by physical treatment are shown in Fig. 5(a, b). The images show the cell structure of the bagasse with pits from the intercellular channels in the cell walls.

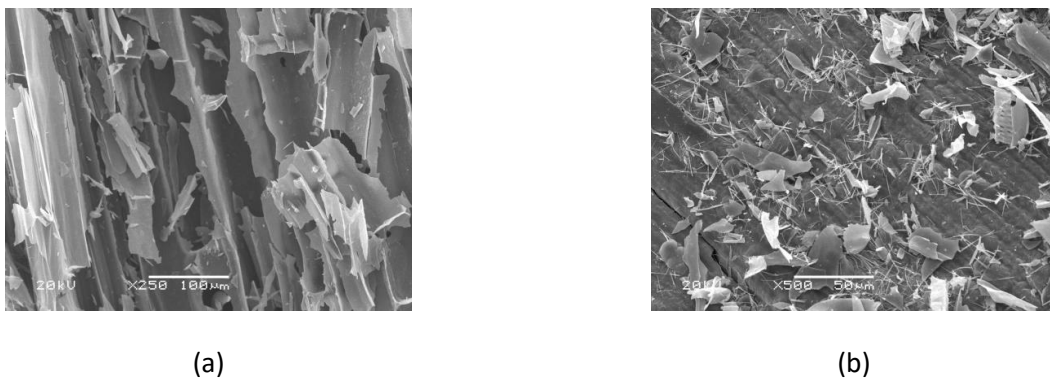


Figure 5. Physical

Micrograph shown in Fig.6 (a, b) reveals that a reduction in the size of the particles occurred after chemical modification of the RBP with H_3PO_4 . It can be observed that the chemical modification process increased the

number of pores and cracks on the fiber surface. Apparent reduction in the size of the particles can be noticed in Fig. 6 (c, d) after thermal treatment. The SEM images of the activated carbon show that the external surfaces are full of cavities and quite irregular. It appears to have numbers of macro pores and so there is a good possibility for dye to be adsorbed into pore.

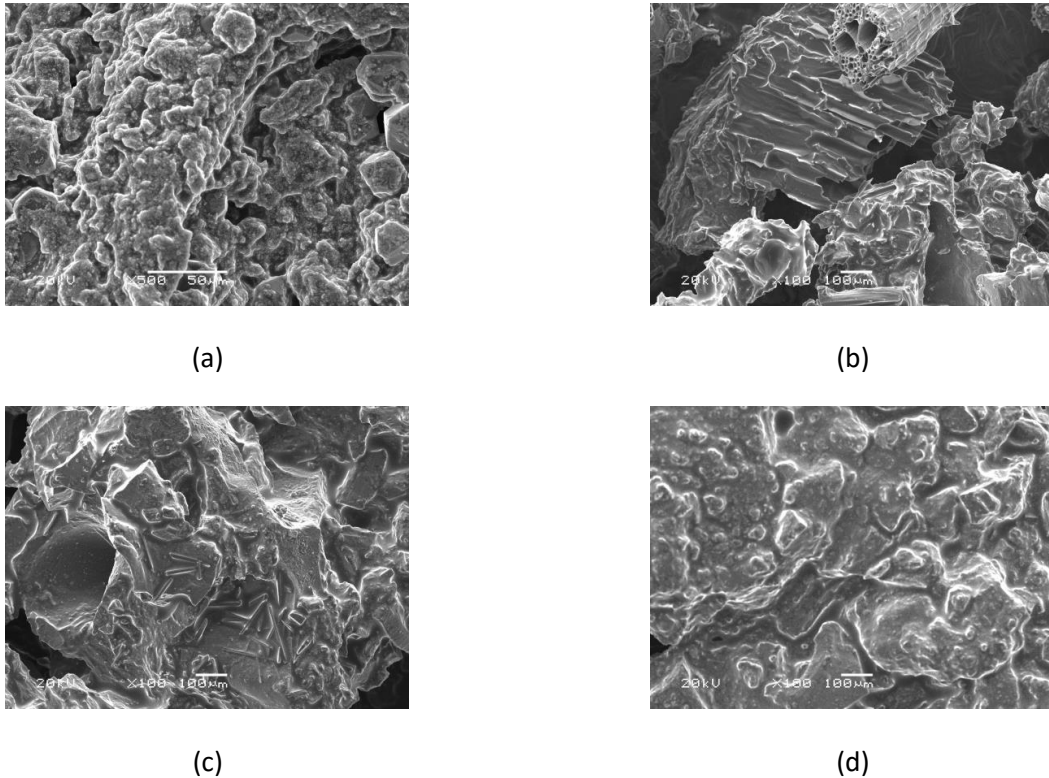


Figure 6. (a) 400 °C, (b) 500 °C, (c) 600 °C, (d) 700 °C

3.2 Adsorption studies

In the next section, the effect of initial dye concentration and contact time are discussed.

3.2.1 Effects of Initial Dye Concentration and Contact Time

The adsorption capacity of raw pith bagasse is studied. The results (Figure 7) indicated that the percentage of dye removal onto raw bagasse pith decreases with an increase in the initial dye concentration. The adsorption of MB dye was very rapid during the first 10 min, and increased gradually during the second 20 min. until reached equilibrium at 60 min. The results showed that the uptake of MB dye by raw bagasse pith depends on MB dose and contact time. This is because MB acts as the driving forces that increase the mass transfer of MB dye from aqueous solution onto the surface of raw bagasse pith. During the adsorption process, solutions with different initial concentrations possibly will reach equilibrium at different times. This may be due to the time required for the dye molecules to encounter the boundary layer effect, then diffuse to the surface of the adsorbent and finally diffuse to the porous structure of the adsorbent (Faust, 1983) Therefore, solutions with low initial concentration (10 ppm) reached equilibrium first at about 30 min, while solutions with high initial concentration of 30 ppm takes longer time and reached equilibrium at 60 min. To ensure complete equilibrium of the data, adsorption samples were collected at 120 min. This may be because the constant number of available sites in raw sugarcane bagasse is easily saturated by the increase of MB, which would lead to a decrease in the removal percentage of MB dye. Finally, it's clear that the amount of adsorption for dye removal is highly dependent on the initial dye concentration. The effect of initial dye concentration

depends on the immediate relation between the concentration of the dye and the available sites on an adsorbent surface. In general, the percentage of dye removal decreases with an increase in the initial dye concentration, which may be due to the saturation of adsorption sites on the adsorbent surface (Senthilkumar *et al.*, 2005).

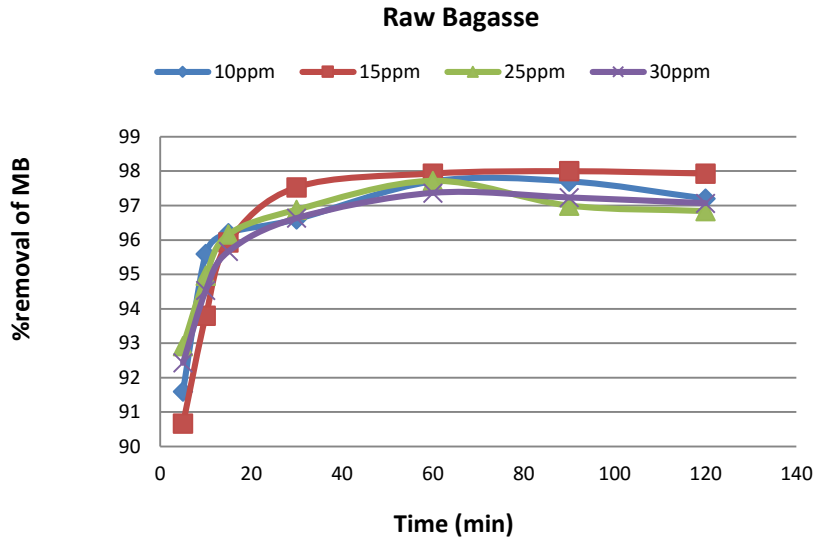


Figure 7. The variation of adsorption capacity with adsorption time at various initial MB concentrations at room temperature

3.2.2 Effects of initial dye concentration and contact time on activated carbon physically prepared

Effect of contact time on adsorption of cationic dye by activated carbon physically prepared is presented in Fig. 8.

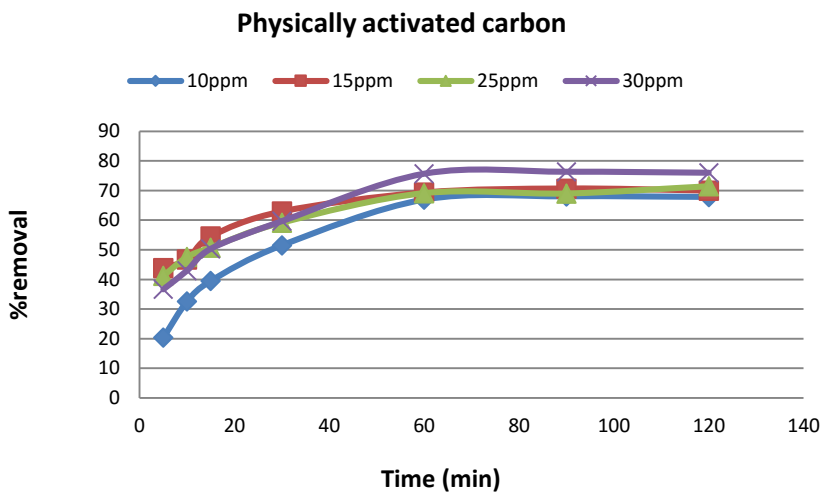


Figure 8. Effect of initial concentration and contact time on the adsorption of MB dye for activated carbon physically prepared

It indicated that the contact time needed for MB solutions with initial concentrations of 10–30 ppm to reach equilibrium is 60 min. However, the experimental data were measured for 2h to make sure that full equilibrium was attained. As can be seen from Fig. 8, the amount of MB adsorbed onto the activated carbon increased with time and, at some point in time, it reached a constant value beyond which no more MB was further removed from the solution. At this point, the amount of the dye desorbing from the activated carbon was in a state of dynamic equilibrium with the amount of the dye being adsorbed onto the activated carbon. The amount of dye adsorbed at the equilibrium time reflects the maximum adsorption capacity of the adsorbent under those operating conditions. The adsorption capacity at the first five minutes increased from 20 to 40 mg g⁻¹ with an increase in the initial dye concentrations from 10 to 30 ppm. Three consecutive mass transport steps are associated with the adsorption of solute from solution by porous adsorbent (Aboul-Fetouh, 2010). First, the adsorbate migrates through the solution, i.e., film fusion, followed by solute movement from particle surface into interior site by pore diffusion and finally the adsorbate is adsorbed into the active sites at the interior of the adsorbent particle. This phenomenon takes relatively long contact time. A similar phenomenon was observed for the adsorption of methylene blue from aqueous solution on activated carbon and the equilibrium time was 60 min (Faust, 1983).

3.2.3 Effect of contact time and initial dye concentration on dye removal of activated carbon chemically prepared

The variations in dye adsorption per unit weight of MB with contact time at different initial concentrations of 10, 15, 25 and 30 ppm for the samples which chemically thermally prepared at 400-700 °C are presented in Figure 9.

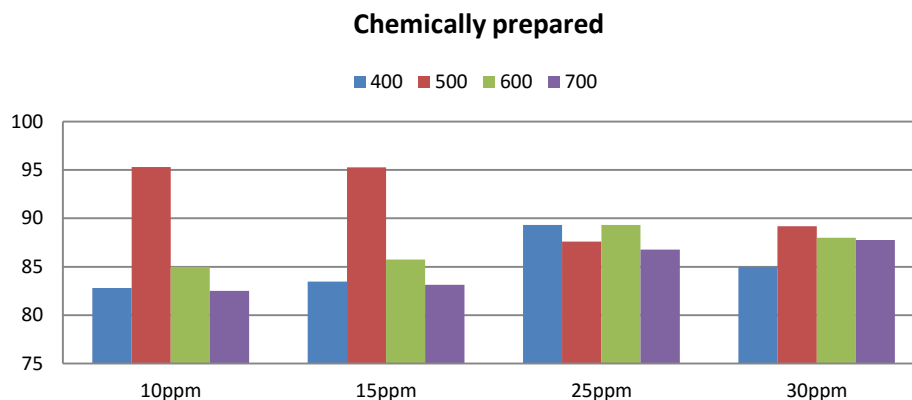


Figure 9. Effect of initial dye concentration and contact time on the adsorption of MB dye onto activated carbon chemically prepared at different temperatures

From the figure it can be observed that the rapid adsorption of dye takes place within the contact time of 5 minutes and there after adsorption process becomes slow. Further experiments were conducted with the contact time of 120 minutes duration. From the figure it can be observed that dye uptake increases with increase in dye concentration. Increase in dye uptake was due to the availability of higher amount of dye molecules in the solution. However, at the same time percent removal of dye was decreased. From the above observation, it is evident that for higher initial concentration of dye, the adsorption is very fast. The percentage removal of dye decreased with increasing initial dye concentration and takes longer time to reach equilibrium because of the fact that with increase in dye concentration, there will be increased competition for the active adsorption sites and the adsorption process will increasingly slow down. This explains the more adsorption time for higher concentration. In the process of dye adsorption, the dye molecules have to first

encounter the boundary layer effect, then adsorb from the surface and, finally, they have to diffuse into the porous structure of the adsorbent. This phenomenon will take a relatively longer contact time. The initial rapid phase may also be due to the increased number of vacant sites available at the initial stage. By comparing the prepared samples at different temperatures, it's clear that the activated carbon prepared at 500 °C is the most effective one reach equilibrium after 60 min.

3.3 Isotherm study

Modeling of experimental adsorption isotherm data is an essential way for predicting the mechanisms of adsorption. Several models have been studied to describe experimental data of adsorption isotherm three famous isotherm equations are the Langmuir, Freundlich and Temkin were employed for further interpretation of the obtained adsorption data.

3.3.1 Langmuir isotherm model

The basic assumption of Langmuir adsorption isotherm is based on:

1. The Langmuir isotherm has a theoretical justification.
2. Monolayer coverage of the adsorbate on the surface of adsorbent.
3. Adsorption is a reversible process.
4. The adsorbed molecules do not move on the surface of the adsorbent.
5. They can be lost back to the solution and the enthalpy of adsorption is the same for all molecules independently of how many have been adsorbed.
6. The Langmuir isotherm typically represents well data for single components.

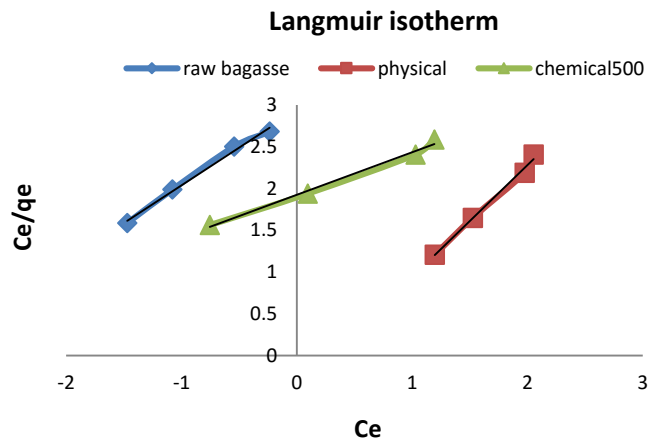


Figure 10. The linearization of adsorption isotherms for methylene blue ions adsorption by sugar bagasse at different condition

The equation that describes the Langmuir isotherm model is given in the following linear form:

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

Where

C_e is the final equilibrium concentration of adsorbate after adsorption has occurred, mg l^{-1}

q_e is the adsorbent phase concentration after equilibrium, $\text{mg adsorbate/g adsorbent}$

b is the equilibrium adsorption constant which is related to the affinity of the bending sites, (l mg^{-1}) .

q_m is the maximum adsorption amount of adsorbate, (mg g^{-1}) (Naiya, 2009).

Figure (10) shows that a linear plot of C_e/q_e against C_e given the slope = q_m and intercept = $1/b \cdot q_m$. (Kumar, 2009).

3.3.2. Freundlich isotherm model

The equation that describes the Freundlich isotherm model is given in the following linear form:

$$\ln q_e = \frac{1}{n} \ln C_e + \ln K_f \quad (5)$$

where

K_f is Freundlich constants that can be related to the adsorption capacity.

n is Freundlich constants that can be related to the adsorption intensity

Figure (11) shows that a linear plot $\ln q_e$ against $\ln C_e$ given the slope = $1/n$ and intercept = $\ln K_f$. The linearization equations, the corresponding parameters and the correlation coefficients of Langmuir and Freundlich are given in Table (1).

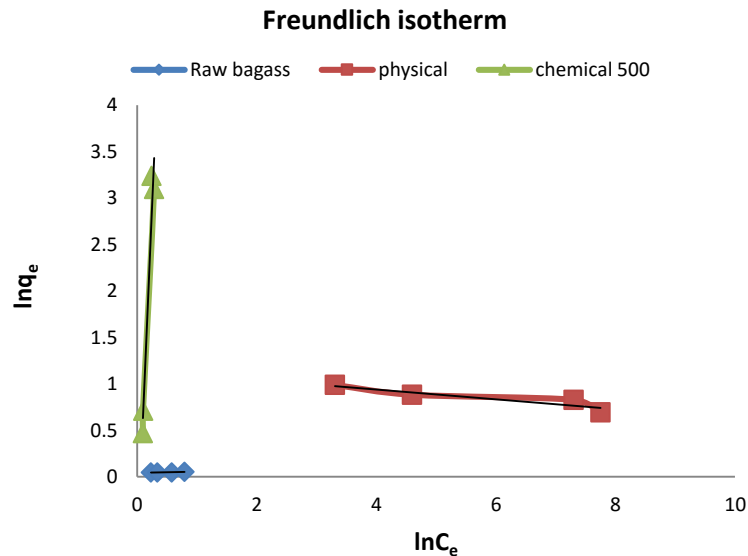


Figure 11. The linearization adsorption isotherms for methylene blue ions adsorption by sugar bagasse at different condition

3.3.3. Temkin isotherm

The Temkin isotherm equation assumes that the heat of adsorption of all the molecules in layer decreases linearly with coverage due to adsorbent-adsorbate interactions, and that the adsorption is characterized by a uniform distribution of the bonding energies, up to some maximum binding energy. (Oladoja, 2008).

The Temkin isotherm is given as:

$$q_e = B_1 \ln(k_t C_e) \quad (6)$$

where

k_t is the equilibrium binding constant corresponding to the maximum binding energy, ($\text{dm}^3 \text{mol}^{-1}$).

B_1 is a constant related to the heat of adsorption.

A plot of q_e versus $\ln C_e$ enables the determination of the isotherm constants B_1 and k_t from the slope and the intercept, respectively.

Temkin isotherm equation contains a factor that explicitly takes into the account the adsorbing species–adsorbent interactions (Srivastava, 2007).

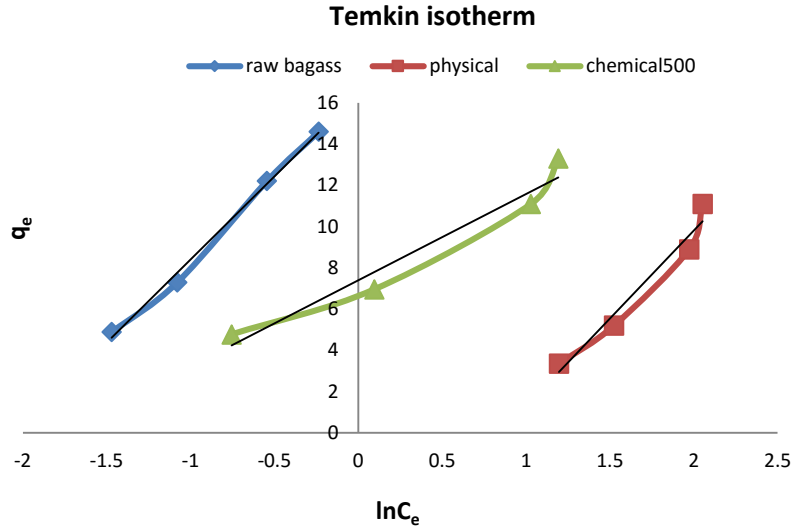


Figure 12. The linearization adsorption isotherms for methylene blue ions adsorption by sugar bagasse at different condition

Table (1) summarized the results of the isothermal constant comparison between raw, physical and chemical treated samples. For the correlation coefficients (R^2), Langmuir model gave the highest value for all samples followed by Temkin model. But for Freundlich model the results seemed to be not fitted with this type of isothermal model. Also in Langmuir model, R_L values is < 1 this indicate that the type of isotherm is favorable.

Table 1. Isotherm parameters for removal of methylene blue by modified and unmodified sugarcane Bagasse

Isotherm	Parameters			
	Raw	Physical	Chemical	
Langmuir model	R^2	0.991	0.992	0.99
	Q_0	1.1087	0.7457	1.9608
	b	0.3068	-3.345	0.26507
	R_L	0.115	-0.0121	0.13118
Freundlich model	R^2	0.716	0.844	0.951
	N_f	83.33	-19.23	0.065
	K_f	-3.1466	1.152	- 0.866
Temkin model	R^2	0.994	0.955	0.951
	A	0.7128	-0.865	1.769
	B	8.070	8.548	9.179

4. Conclusion

It is observed that activated carbon prepared from raw bagasse pith, after only one chemical modification step is going to be efficient for removing MB from aqueous solutions by adsorption. Equilibrium adsorption times were found to be 1 h for MB. The adsorption isotherm equations like Freundlich, Langmuir and Temkin were applied to check the feasibility of adsorption process. On the basis of correlation coefficient values it is concluded that the mechanism of adsorption of dyes in the raw, physical and chemical treated sugarcane bagasse follows both Langmuir and Temkin adsorption isotherms. Waste treatment by adsorption using low cost adsorbent is a demanding area as it has double benefits i.e. water treatment and waste management.

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